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(54) [Title of the Invention]

EXPOSURE APPARATUS, EXPOSURE METHOD, AND DEVICE

MANUFACTURING METHOD

(57) [Abstract]

[Problem]

To realize a high-precision transfer of a fine pattern.

[Means for Resolution]

By an illuminating optical system IL including a light source 1 and a polarization control element 5, a reticle 18 having a pattern formed to include a major line pattern extending in an X direction is irradiated with a slit-shaped illumination light  $I_4$  which has a main component of a linear polarization in a polarization direction parallel to the X direction and which has a longitudinal direction in the X direction. The reticle 18 held on a reticle stage 19 and a wafer 25 held on a wafer stage 26 are moved along a Y direction by the stages 19 and 26 so that a projected image by a projecting optical system 24 of the pattern of the reticle 18 is sequentially transferred to the wafer 25.

[Selected Drawing] Fig. 1

[Claims]

[Claim 1]

A scanning type exposure apparatus for transferring the image of a pattern formed on a mask onto a substrate, characterized: by comprising

a stage device for moving said mask and said substrate relatively along a first direction,

an illuminating optical system for illuminating said mask, and a projecting optical system for projecting the pattern of said mask on said substrate; and

in that said illuminating optical system illuminates said mask such that the polarization state of the illumination light to irradiate said substrate through said projecting optical system may make a main component of the linear polarization in the polarization direction parallel to a second direction perpendicular to said first direction.

[Claim 2]

An exposure apparatus as set forth in claim 1, characterized in that the illumination light to irradiate said substrate has a degree of polarization of 80 % or more.

[Claim 3]

An exposure apparatus as set forth in claim 1 or 2, characterized in that said illuminating optical system includes a shaping device for shaping the sectional shape of the illumination light to irradiate said substrate, into a slit shape having a longitudinal direction in said second direction.

[Claim 4]

An exposure apparatus as set forth in any of claims 1 to 3,

characterized in that said stage device holds said mask such that the longitudinal direction and said second direction of line patterns of the patterns formed on said mask are substantially parallel.

[Claim 5]

An exposure apparatus as set forth in any of claims 1 to 4, characterized in that said illuminating optical system includes an adjusting device for adjusting the light from a light source, into an illumination light having a main component of a linear polarization in a polarization direction parallel to said second direction.

[Claim 6]

An exposure apparatus as set forth in any of claims 1 to 5, characterized in that said illuminating optical system includes a switching mechanism for switching it selectively whether the illumination light to irradiate said substrate through said projecting optical system is an illumination light having a main component of the linear polarization in the polarization direction parallel to said second direction, or a natural light or a circular polarization or an elliptical polarization.

[Claim 7]

An exposure apparatus for transferring the image of a pattern formed on a mask, under an illumination light, onto a substrate through a projecting optical system, characterized by comprising:

a shaping device for shaping the exposure view field exposure field of said projecting optical system on said substrate, into a shape having a longitudinal direction; and

an adjusting device for adjusting at least one of the polarization direction of said illumination light and said shaping device, to make the longitudinal direction of the exposure view

fieldexposure field on said substrate and the polarization direction of said illumination light parallel to each other.

[Claim 8]

An exposure apparatus as set forth in claim 7, characterized:  
by further comprising an illuminating optical system for illuminating said mask with said illumination light; and  
in that said shaping device is disposed in said illuminating optical system.

[Claim 9]

An exposure apparatus as set forth in claim 7, characterized in that said adjusting device adjusts the light from the light source, into an illumination light having a main component of the polarization direction parallel to the longitudinal direction of the exposure view fieldexposure field on said substrate.

[Claim 10]

An exposure apparatus as set forth in any of claims 7 to 9, characterized:  
by further comprising a stage device for moving said mask and said substrate relatively along a first direction; and  
in that the longitudinal direction of said exposure view fieldexposure field is perpendicular to said first direction.

[Claim 11]

An exposure apparatus as set forth in any of claims 1 to 10, characterized:  
in that said illuminating optical system includes a plurality of optical elements formed of a fluoride crystal; and  
in that said plural optical elements are different in the optical axis direction of said illuminating optical system between the kind

of the crystalline axis of optical elements of one portion and the kind of the crystalline axis of the optical elements of the other portion.

[Claim 12]

An exposure apparatus as set forth in claim 11, characterized in that the crystalline axis of the optical elements of said one portion and perpendicular to the optical axis direction of said illuminating optical system and the crystalline axis of the optical elements of said other portion and perpendicular to the optical axis direction of said illuminating optical system are arranged to rotate relative to each other on the center axis or the optical axis of said illuminating optical system.

[Claim 13]

An exposure method for transferring, while moving a mask having a pattern formed thereon and a substrate relative to each other along a first direction, the pattern of said mask to said substrate through a projecting optical system,

characterized in that an illumination light to irradiate said substrate is an illumination light of a slit shape having a longitudinal direction in a second direction perpendicular to said first direction, and having a main component of a linear polarization parallel to said second direction.

[Claim 14]

An exposure method as set forth in claim 13, characterized in that the exposure is performed such that, of said pattern formed on said mask, a line pattern is set to have its longitudinal direction substantially parallel to said second direction.

[Claim 15]

An exposure method as set forth in claim 13 or 14, characterized in that said illumination light has a degree of polarization of 80 % or more.

[Claim 16]

An exposure method for transferring, under an illumination light, the image of a pattern formed on a mask, onto a substrate through a projecting optical system, characterized by:

shaping the exposure field of viewexposure field of said projecting optical system on said substrate into a shape having a longitudinal direction; and

transferring the image of the pattern of said mask onto said substrate such that the polarization direction of an illumination light to irradiate said substrate is parallel to the longitudinal direction of the exposure view fieldexposure field on said substrate.

[Claim 17]

An exposure method as set forth in claim 16, characterized in that the exposure is performed such that, of said pattern formed on said mask, a line pattern is set to have its longitudinal direction substantially parallel to the longitudinal direction of said exposure view fieldexposure field.

[Claim 18]

An exposure method as set forth in claim 16 or 18, characterized in that, when the exposure is performed with said mask and said substrate being relatively moved along a first direction, the longitudinal direction of said exposure view fieldexposure field is perpendicular to said first direction.

[Claim 19]

A device manufacturing method using an exposure apparatus as

set forth in any of claims 1 to 12, characterized:

in that a silicon crystal substrate, in which a direction normal to its surface is substantially aligned with a [111] crystalline axis, is used as said substrate; and

in that said substrate is exposed to said illumination light such that either a [11-2] crystalline axis perpendicular to said [111] crystalline axis or a crystalline axis equivalent to the former is aligned with said second direction or the longitudinal direction of said exposure view fieldexposure field.

[Claim 20]

A device manufacturing method as set forth in claim 19, characterized in that said substrate is so exposed to the gate pattern formed on said mask, as to be substantially parallel to either said [11-2] crystalline axis or a crystalline axis equivalent to the former.

[Claim 21]

A device manufacturing method using an exposure apparatus as set forth in any of claims 1 to 12, characterized:

in that a silicon crystal substrate, in which a direction normal to its surface is substantially aligned with a [110] crystalline axis, is used as said substrate; and

in that said substrate is exposed to said illumination light such that either a [00-1] crystalline axis perpendicular to said [110] crystalline axis or a crystalline axis equivalent to the former is aligned with said second direction or the longitudinal direction of said exposure view fieldexposure field.

[Claim 22]

A device manufacturing method as set forth in claim 21,

characterized in that said substrate is so exposed to the gate pattern formed on said mask, as to be substantially parallel to either said [00-1] crystalline axis or a crystalline axis equivalent to the former.

[Claim 23]

A device manufacturing method using an exposure apparatus as set forth in any of claims 1 to 12, characterized:

in that a semiconductor wafer, in which a semiconductor crystalline structure of its surface layer is distorted at least in one predetermined direction, is used as said substrate; and

in that said substrate is exposed such that the direction for the highest mobility of at least electrons or holes in said surface layer is aligned with either said first direction or a direction perpendicular to the longitudinal direction of said exposure view fieldexposure field.

[Claim 24]

A device manufacturing method as set forth in claim 23, characterized in that said surface layer is a silicon crystalline layer.

[Claim 25]

A device manufacturing method using an exposure apparatus as set forth in any of claims 13 to 18, characterized:

in that a silicon crystal substrate, in which a direction normal to its surface is substantially aligned with a [111] crystalline axis, is used as said substrate; and

in that said substrate is exposed to said illumination light such that either a [11-2] crystalline axis perpendicular to said [111] crystalline axis or a crystalline axis equivalent to the former is

aligned with said second direction or the longitudinal direction of said exposure view fieldexposure field.

[Claim 26]

A device manufacturing method as set forth in claim 25, characterized in that said substrate is so exposed to the gate pattern formed on said mask, as to be substantially parallel to either said [11-2] crystalline axis or a crystalline axis equivalent to the former.

[Claim 27]

A device manufacturing method using an exposure method as set forth in any of claims 13 to 18, characterized:

in that a silicon crystal substrate, in which a direction normal to its surface is substantially aligned with a [110] crystalline axis, is used as said substrate; and

in that said substrate is exposed to said illumination light such that either a [00-1] crystalline axis perpendicular to said [110] crystalline axis or a crystalline axis equivalent to the former is aligned with said second direction or the longitudinal direction of said exposure view fieldexposure field.

[Claim 28]

A device manufacturing method as set forth in claim 27, characterized in that said substrate is so exposed to the gate pattern formed on said mask, as to be substantially parallel to either said [00-1] crystalline axis or a crystalline axis equivalent to the former.

[Claim 29]

A device manufacturing method using an exposure method as set forth in any of claims 13 to 18, characterized:

in that a semiconductor wafer, in which a semiconductor crystalline structure of its surface layer is distorted at least in one predetermined direction, is used as said substrate; and

in that said substrate is exposed such that the direction for the highest mobility of at least electrons or holes in said surface layer is aligned with either said first direction or a direction perpendicular to the longitudinal direction of said exposure view fieldexposure field.

[Claim 30]

A device manufacturing method as set forth in claim 29, characterized in that said surface layer is a silicon crystalline layer.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention Belongs]

The present invention relates to an exposure apparatus, an exposure method and a device manufacturing method, which are used when a semiconductor integrated circuit, a liquid crystal display element, a thin film magnetic head, another micro device, or a photomask is manufactured by using a photolithographic technique.

[0002]

[Prior Art]

When a fine pattern of an electronic device such as a semiconductor integrated circuit or a liquid crystal display is to be formed, there is used a method for reducing, exposing and transferring the pattern of a reticle (a mask, as also called so), which is drawn by proportionally enlarging a pattern to be formed by four or five times, to an exposed substrate such as a wafer by using

a projecting exposure apparatus.

[0003]

The projecting exposure apparatus used in the transfer has been shifted in its exposure wavelength to a shorter side so as to match the miniaturization of the semiconductor integrated circuit. At present, 248 nm of a KrF excimer laser is becoming the mainstream, but a shorter wavelength of 193 nm of an ArF excimer laser is coming into the practical stage. There is also proposed a projecting exposure apparatus using a light source of a shorter wavelength band, as called the "vacuum ultraviolet range", such as a F<sub>2</sub> laser having a wavelength of 157 nm or an Ar<sub>2</sub> laser having a wavelength of 126 nm.

[0004]

On the other hand, a high resolution can be made not only by shortening the wavelength but also by enlarging the numeral aperture (NA) of an optical system. Thus, a development has been made to enlarge increase the NA of the optical system more. For realizing the high resolution, it is necessary to reduce the aberration of the projecting optical system. In the process for manufacturing the projecting optical system, therefore, a wavefront aberration measurement using the optical interference is performed to measure the residual aberration in an accuracy of about 1/1000 of the exposure wavelength so that the projecting optical system is adjusted on the basis of the measured value.

[0005]

These large NA and small aberration are easier to realize for the optical system of the smaller field of view. However, the exposure apparatus has the processing ability (or throughput) improved the better for the larger view field (or exposure field). In order to

acquire a substantially large exposure field by using a projecting optical system having a small view field but a large NA, the recent mainstream is the scan type exposure apparatus, in which the mask and the wafer are relatively scanned during the exposure while keeping their focusing imaging relation.

[0006]

The projecting optical system, as used in the scan type exposure apparatus, has a good image rangeimage area (or a good exposure view fieldexposure field) of a rectangular type, which is generally long in one direction and short in a perpendicular direction. This optical system may use a reflection optical systemcataptric optical system but generally uses a refractive optical systemdioptric optical system. In this case, the aforementioned rectangular exposure view fieldexposure field is generally formed from the circular shape or the intrinsic good image rangeimage area, as made of a combination of circular lenses, of the refractive optical systemdioptric optical system, to a rectangular shape, which includes the center of that circle and is inscribed with that circle. This is because that rectangular view field can maximize the length of the longer side of the view field and accordingly the efficiency.

[0007]

In case, however, a cata-diopticcatadioptic system is adopted as the projecting optical system, the good image rangeimage area of the projecting optical system is not always the circular shape. Therefore, the exposure view fieldexposure field is neither always the rectangular shape including the diameter of the circle, but may be a rectangle having its center eccentric from the center of the circle.

[0008]

The direction for a relative scan is perpendicular to the longer side direction. As a result, the view field of the projecting optical system in the shorter direction of the rectangle is enlarged by that relative scanning so that the narrow view field in the shorter side direction raises no problem.

[0009]

[Problems that the Invention is to Solve]

As described above, the exposure area to be exposed by the scan type exposure apparatus is obtained for one direction by the view field of the projecting optical system, and the focusing performanceimaging performance of the projecting optical system also changes according to that position so that the transfer characteristics of the pattern also change.

[0010]

On the other hand, the perpendicular direction is enlarged by the relative scan between the reticle and the wafer, and the focusing performanceimaging performance of the projecting optical system is uniform in its direction.

[0011]

Generally in the optical system, there is left the aberration to degrade the focusing characteristicimaging characteristics. In the projecting optical system for the projecting exposure apparatus, the residual aberration is extremely less than that of an optical system for another application. It is, however, unavoidable to leave the aberration of some extent.

[0012]

As these residual aberrations, there are the components (or the

radial components) to blur the transfer image in the radial direction from the optical axis of the projecting optical system to the circumference, and the components (or the concentric components) to blur the transfer image in the concentric direction on the optical axis of the projecting optical system. Of these, the radial components are generally larger.

[0013]

The aberrations of the radial components are coma aberrations and chromatic aberrations of a magnificationmagnification chromatic aberration. The coma aberrations are hard to correct on the design and from the manufacturing error, and are difficult to eliminate completely. The corrections of the chromatic aberrations of the magnificationmagnification chromatic aberration require a large quantity of expensive lens material for correcting the secondary spectrum of the lenses, so that the lens price extremely rises for the complete corrections. On the other hand, the influences of the chromatic aberrations can be reduced by narrowing (for the narrow band) the wavelength width of a light source such as a laser (e.g., an excimer laser). As the laser has the narrower band, however, its output drops so that the exposure light illuminance on the wafer surface drops. As a result, the elongation of the illumination time is needed to lower the processing ability (or the throughput) of the exposure apparatus so that the production yield drops. Because of a lifetime of the optical elements needed for the narrower laser band, the optical elements have to be periodically replaced to raise the running cost for the laser.

[0014]

The present invention has been made to solve those problems,

and has an object to realize an exposure apparatus, an exposure method and a device manufacturing method, which can perform a high-precision transfer of important ones of patterns to be transferred to a substrate, and which can transfer a pattern equivalent to or higher than that of the prior art even if when they use an optical system having the aberrations of concentric components such as the magnification chromatic aberrations or the partial coma aberrations left therein.

[0015]

[Means for Solving the Problems]

In the description to be made under this title, the invention will be described in connection with the reference numerals shown in the drawings explaining the mode of embodiments. However, the individual components of the invention should not be limited to those designated by those reference numerals in the drawings.

[0016]

In order to solve the aforementioned problems, according to a first aspect of the invention, there is provided a scanning type exposure apparatus for transferring the image of a pattern formed on a mask (18) onto a substrate (25) comprising a stage device (19, 26) for moving said mask and said substrate relatively along a first direction (a Y direction), an illuminating optical system (IL) for illuminating said mask, and a projecting optical system (24) for projecting the pattern of said mask on said substrate, wherein said illuminating optical system has a function to illuminate said mask such that the polarization state of the illumination light to irradiate said substrate through said projecting optical system may make a main component of the linear polarization in the polarization direction parallel to a second direction perpendicular to said first

direction. Here, "to make a main component of the linear polarization" means the complete polarization, in which said illumination light is composed of only said linear polarization, or the partial polarization including the natural light or another polarization. It is desired that said illumination light has a degree of polarization of 80 % or more, in case it is a partial polarization. The "degree of polarization" is the ratio of the energy of said linear polarization of said partial polarization to the whole energy. Moreover, the "polarization direction" is the direction of the electric- field vector of a light.

[0017]

According to the invention, when the pattern of the mask is to be transferred to the substrate, the polarization state of the illumination light (or the exposure light) to irradiate the substrate is made to have the main component of the linear polarization of the polarization direction parallel to the second direction perpendicular to the first direction as the moving direction, and the pattern of the mask is exposed and transferred to the substrate. Of the pattern formed on the mask, the contrast of the projected image on the line pattern extending in the direction along said second direction can be raised to transfer the fine pattern highly precisely.

[0018]

In the invention, said illuminating optical system (IL) includes a shaping device (14) for shaping the sectional shape of the illumination light to irradiate said substrate, into a slit shape (a rectangular shape, a strip shape) having a longitudinal direction in said second direction. As a result, the adverse influences due to the residual aberration of the projecting optical system can be

alleviated relaxed to make the transfer more precise. Here, said mask and said substrate are in the focusing relation (in which the pattern of the mask is projected). Therefore, the sectional shape of the illumination light on said substrate can be made into the slit shape by forming the sectional shape of the illumination light ( $I_4$ ) to irradiate said mask (18) into the slit shape.

[0019]

In these cases, said stage device (19, 26) holds said mask such that the longitudinal direction and said second direction (or an X direction) of line patterns (32 to 34) of the patterns formed on said mask (18) are substantially parallel. In case said line patterns are two or more kinds in mutually different directions (e.g., mutually perpendicular directions), said mask is desirably held such that, of said line patterns, a major line pattern to perform the highly precise transfer has a longitudinal direction substantially parallel to said second direction. Since the exposure precision on the line pattern extending in the direction along the second direction can be raised, as described above, the exposure precision of said main line patterns can be enhanced by setting the main line pattern positively along said second direction.

[0020]

In the invention, said illuminating optical system (IL) can include an adjusting device (5) for illuminating said substrate (25) with the light ( $I_0$ ) fed from a light source (1), as an illumination light having a main component of a linear polarization in a polarization direction parallel to said second direction (or an X direction) through said projecting optical system (24). In case the light source (1) for feeding supplying the light to the illuminating

optical system (IL) emits the light having a main component of the linear polarization in the polarization direction parallel to a specific direction, said adjusting device (5) is exemplified by a polarization rotating device (e.g., a 1/2 wavelength platewave-plate), in which the polarization direction of said linear polarization of the illumination light to irradiate said substrate (25) rotates the polarization plane along said second direction. However, that adjusting device (5) need not be used, but the optical system position relation between said light source (1) and said illuminating optical system (IL) may be so suitably set that the illumination light having the main component of the linear polarization in the polarization direction parallel to said second direction is guided to irradiate said substrate through said projecting optical system. In case, on the other hand, the light source (1) to feed the light to the illuminating optical system (IL) emits a natural light or another polarization light (e.g., a circle polarization or an elliptic polarization), said adjusting device (5) is exemplified by a linear polarization device (e.g., a linear polarization elementpolarizer or a 1/4 wavelength platewave-plate) for adjusting the light from said light source into an illumination light having a main component of the linear polarization of the polarization direction parallel to said second direction.

[0021]

In the invention, said illuminating optical system (IL) can include a switching mechanism for switching it selectively whether the illumination light to irradiate said substrate (25) through said projecting optical system (24) is an illumination light having a main component of the linear polarization in the polarization direction

parallel to said second direction, or a natural light or a circular polarization or an elliptical polarization. As a result, the proper illumination light can be selected according to the contents of the pattern to be exposed and transferred.

[0022]

In order to solve the aforementioned problems, according to a second aspect of the invention, there is provided an exposure apparatus for transferring the image of a pattern formed on a mask (18), under an illumination light ( $I_4$ ), onto a substrate (25) through a projecting optical system (24) comprising: a shaping device (14) for shaping the exposure view fieldexposure field of said projecting optical system (24) on said substrate, into a shape having a longitudinal direction; and an adjusting device (5) for adjusting at least one of the polarization direction of said illumination light ( $I_4$ ) and said shaping device (14), to make the longitudinal direction of the exposure view fieldexposure field of said projecting optical system on said substrate and the polarization direction of said illumination light to irradiate said substrate parallel to each other.

[0023]

The exposure apparatus of the invention can comprise an illuminating optical system (IL) for illuminating said mask with said illumination light ( $I_4$ ), and said shaping device (14) can be disposed in said illuminating optical system (IL).

[0024]

In the invention, moreover, said adjusting device (5) can adjust the light from the light source, into an illumination light having a main component of the linear polarization direction parallel to the longitudinal direction of the exposure view fieldexposure field of

said projecting optical system on said substrate.

[0025]

Moreover, the exposure apparatus of the invention can comprise a stage device (19, 26) for moving said mask (18) and said substrate (25) relatively along a first direction (or a Y direction), and the longitudinal direction of said exposure view field/exposure field can be the direction (or an X direction) perpendicular to said first direction.

[0026]

According to a third aspect of the invention, in an exposure apparatus according to the first or second aspect of the invention, said illuminating optical system includes a plurality of optical elements formed of a fluoride crystal, and said plural optical elements are different in the optical axis direction of said illuminating optical system between the kind of the crystalline axis of optical elements of one portion and the kind of the crystalline axis of the optical elements of the other portion.

[0027]

In this case, the crystalline axis of the optical elements of said one portion and perpendicular to the optical axis direction of said illuminating optical system and the crystalline axis of the optical elements of said other portion and perpendicular to the optical axis direction of said illuminating optical system can be arranged to rotate relative to each other on the center axis or the optical axis of said illuminating optical system.

[0028]

Here, the phrase "the kind of the crystalline axis of optical elements of one portion and the kind of the crystalline axis of the

optical elements of the other portion are different" means that, in case the crystalline axis of the illuminating optical system axial direction of said optical elements of one portion is the [111] crystalline axis, for example, the crystalline axis of the illuminating optical system axial direction of said optical elements of the other portion is the crystalline axis (e.g., the [100] crystalline axis) other than the [111] crystalline axis.

[0029]

By arranging the plural optical elements in the predetermined relation, as described above, the birefringence owned by said optical elements can be corrected or offset to reduce the adverse influences to the polarization direction or the polarization state of the illumination light by said birefringence.

[0030]

In order to solve the aforementioned problems, according to a fourth aspect of the invention, there is provided an exposure method for transferring, while moving a mask (18) having a pattern formed thereon and a substrate (25) relative to each other along a first direction (or a Y direction), the pattern of said mask to said substrate through a projecting optical system, wherein an illumination light to irradiate said substrate is an illumination light of a slit shape having a longitudinal direction in a second direction perpendicular to said first direction, and having a main component of a linear polarization parallel to said second direction. In this case, of said pattern formed on said mask, a line pattern is desirably set to have its longitudinal direction substantially parallel to said second direction.

[0031]

Here, the "illumination light having a main component of a linear polarization" means either the complete polarization, in which said illumination light has only said linear polarization as a component, or a natural light or a partial polarization containing another polarization. It is desired that said illumination light has a degree of polarization of 80 % or more in the case of the partial polarization. The "degree of polarization" is the ratio of the energy of said linear polarization of said partial polarization to the whole energy. Moreover, the "polarization direction" is the direction of the electric-field vector of a light.

[0032]

According to the invention, the linear polarization of the polarization direction parallel to the second direction perpendicular to the first direction as the moving direction is used as the main component, and the exposure is made by using the slit-shaped illumination light having the longitudinal direction in said second direction. Of the pattern formed on the mask, the contrast of the projected image on the line pattern extending in the direction along said second direction can be raised, and the adverse influences due to the aberration of the projecting optical system for projecting the pattern of the mask on the substrate can be alleviated relaxed to transfer the fine pattern highly precisely.

[0033]

In order to solve the aforementioned problems, according to a fifth aspect of the invention, there is provided an exposure method for transferring, under an illumination light ( $I_4$ ), the image of a pattern formed on a mask (18), onto a substrate (25) through a projecting optical system (24). The exposure method is characterized

by shaping the exposure field of viewexposure field of said projecting optical system (24) into a shape having a longitudinal direction, and by transferring the image of the pattern of said mask onto said substrate such that the polarization direction of an illumination light ( $I_4$ ) is parallel to the longitudinal direction of said exposure view fieldexposure field.

[0034]

In the invention, the exposure can be performed such that, of said pattern formed on said mask, a line pattern is set to have its longitudinal direction substantially parallel to the longitudinal direction of said exposure view fieldexposure field.

[0035]

In the invention, moreover, when the exposure is performed with said mask (18) and said substrate (25) being relatively moved along a first direction (or a Y direction), the longitudinal direction of said exposure view fieldexposure field is perpendicular to said first direction.

[0036]

According to a sixth aspect of the invention, in the exposure apparatus according to the first, second or third aspect of the invention or in the exposure method according to the fourth or fifth aspect of the invention, there is provided a device manufacturing method using an exposure apparatus characterized in that a silicon crystal substrate, in which a direction normal to its surface is substantially aligned with a [111] crystalline axis, is used as said substrate, and

in that said substrate is exposed to said illumination light such that either a [11-2] crystalline axis perpendicular to said [111]

crystalline axis or a crystalline axis equivalent to the former is aligned with said second direction or the longitudinal direction of said exposure view fieldexposure field. In this case, said substrate can be so exposed to the gate pattern formed on said mask, as to be substantially parallel to either said [11-2] crystalline axis or a crystalline axis equivalent to the former. Thus, it is possible to manufacture a semiconductor device capable of acting at a higher speed, and another electronic device.

[0037]

According to a seventh aspect of the invention, in the exposure apparatus according to the first, second or third aspect of the invention or in the exposure method according to the fourth or fifth aspect of the invention, there is provided a device manufacturing method using an exposure apparatus characterized in that a silicon crystal substrate, in which a direction normal to its surface is substantially aligned with a [110] crystalline axis, is used as said substrate, and in that said substrate is exposed to said illumination light such that either a [00-1] crystalline axis perpendicular to said [110] crystalline axis or a crystalline axis equivalent to the former is aligned with said second direction or the longitudinal direction of said exposure view fieldexposure field. In this case, said substrate can be so exposed to the gate pattern formed on said mask, as to be substantially parallel to either said [00-1] crystalline axis or a crystalline axis equivalent to the former. Thus, it is possible to manufacture a semiconductor device capable of acting at a higher speed, and another electronic device.

[0038]

According to an eighth aspect of the invention, in the exposure

apparatus according to the first, second or third aspect of the invention or in the exposure method according to the fourth or fifth aspect of the invention, there is provided a device manufacturing method using an exposure apparatus, characterized in that a semiconductor wafer, in which a semiconductor crystalline structure of its surface layer is distorted at least in one predetermined direction, is used as said substrate, and in that said substrate is exposed such that the direction for the highest mobility of at least electrons or holes in said surface layer is aligned with either said first direction or a direction perpendicular to the longitudinal direction of said exposure view field/exposure field. In this case, said surface layer can be exemplified by a semiconductor wafer owned by a silicon crystalline layer. Thus, it is possible to manufacture a semiconductor device capable of acting at a higher speed, and another electronic device.

[0039]

In Specification of this patent application, the phrase of "the crystalline axis and the equivalent crystalline axis" means a crystalline axis having the order of indexes of a crystalline axis interchanged, and a crystalline axis having signs of at least a portion of their individual indexes partially inverted. In case a crystalline axis is [abc], the following crystalline axes are equivalent:  
[acb], [bac], [bca], [cab], [cba], [-abc], [-acb], [-bac], [-bca],  
[-cab], [-cba], [a-bc], [a-cb], [b-ac], [b-ca], [c-ab], [c-ba],  
[ab-c], [ac-b], [ba-c], [bc-a], [ca-b], [cb-a], [a-bc], [a-cb],  
[-b-ac], [-b-ca], [-c-ab], [-c-ba], [a-b-c], [a-c-b], [b-a-c],  
[b-c-a], [c-a-b], [c-b-a], [-a-b-c], [-a-c-b], [-b-a-c], [-b-c-a],  
[-c-a-b], and [-c-b-a].

[0040]

[Mode of Embodiment of the Invention]

Modes of embodiment of the invention are described in the following with reference to the accompanying drawings.

[0041]

Fig. 1 is a diagram showing a schematic constitution of an exposure apparatus according to a mode of embodiment of the invention. This exposure apparatus is a step-and-scan type (or scanning type) projecting exposure apparatus. Here in the following description, an XYZ orthogonal coordinate system shown in Fig. 1 is set, and description is made with reference to the XYZ orthogonal coordinate system. In the XYZ orthogonal coordinate system, the Y-axis and the Z-axis are set parallel to the sheet face, and the X-axis is set normal to the sheet face. In the shown XYZ coordinate system, the XY plane is set parallel to the horizontal plane, and the Z-axis is set upward of the vertical line. The direction along the Y-axis is the scan (or scanning) direction.

[0042]

A scan type projecting exposure apparatus according to this mode of embodiment is constituted to include a light source 1, an illuminating optical system IL, a projecting optical system 24 and a stage device having a reticle stage 19 and a wafer stage 26.

[0043]

A reticle (or mask) 18 having a pattern to be transferred is sucked and held on the reticle stage 19 placed on a reticle stoolreticle surface plate 22, so that it can be scanned in the Y direction as shown over the reticle stoolreticle surface plate 22 by the reticle stage 19. A reticle side moving mirror 20 is disposed over the reticle stage

19, and a reticle side laser interferometer 21 is arranged to confront the reticle side moving mirror 20. The measured value by the reticle side laser interferometer 21 is fed to the not-shown stage control device so that the actions of the reticle stage 19 are controlled by that stage control device.

[0044]

The reticle 18 sucked and held by the reticle stage 19 is irradiated with an illumination light  $I_4$  by the illuminating optical system IL. The reticle stoolreticle surface plate 22 has an aperture 23 for passing the illumination light  $I_4$  so that the illumination light (or a diffracted light) having passed through the reticle 18 enters the projecting optical system 24 through the aperture 23. By the focusing action of the projecting optical system 24, moreover, the projected image of the pattern on the reticle 18 is formed on a semiconductor wafer (or a sensitive substrate) 25 as the exposed substrate. This projected image photosensitizes the photoresist applied to the surface of the wafer 25 so that the reticle pattern is transferred to the surface of the wafer 25.

[0045]

The wafer 25 is sucked and held by the wafer stage 26 placed on a wafer stoolwafer surface plate 29 so that it can be scanned in the Y direction, as shown, over the wafer stoolwafer surface plate 29 by the wafer stage 26. Over the wafer stage 26, there is disposed a wafer side moving mirror 27, which is confronted by a wafer side laser interferometer 28. The measured value by the wafer side laser interferometer 28 is fed to the stage control device, by which the wafer stage 26 is controlled to move synchronously with the movement of the reticle stage 19. Here, the wafer stage 26 is enabled not only

to scan in the Y direction but also to perform stepping movements in the X direction and in the Y direction. In order to transfer the projected images of the reticle pattern to a plurality of shot areas set all over the surface of the wafer 25, the scanning exposures in the Y direction are repeated while the wafer 25 being sequentially stepwise moved in the XY directions.

[0046]

An illumination light  $I_0$ , as emitted from the light source 1 such as a KrF (krypton-fluorine) excimer laser (having a wavelength of 248 nm), an ArF (argon-fluorine) excimer laser (having a wavelength of 193 nm) or a  $F_2$  (a fluorine molecule) laser (having a wavelength of 157 nm), is fed to the illuminating optical system IL.

[0047]

The illuminating optical system IL has a constitution, as follows. The illumination light  $I_0$  fed from the light source 1 is guided a polarizing mirror 2 and shaping optical systems 3 and 4 so that it enters a polarization control element (or an adjusting device) 5. The detail of this polarization control element 5 will be described hereinafter.

[0048]

An illumination light  $I_1$  having passed through the polarization control element 5 enters a first illumination uniforming member 6 such as a fly-eyefly's eye lens or a diffraction grating. The luminous fluxlight beam having emanated the first illumination uniforming member 6 passes through relay lenses 7 and 8, and enters a second illumination uniforming member 9 such as a fly-eyefly's eye lens. The illumination uniforming member 9 is equipped on its emanating side face with an illumination aperture stop (or a  $\sigma$  diaphragm) 10. This

illumination aperture stop 10 can be exemplified by a circular stop (or an iris stop) having a variable radius, an ring-shaped annular-shaped stop or a modified illumination stop having a plurality of apertures. These stops are arranged on a rotatable revolver so that they can be selectively arranged by rotating and positioning the revolver properly.

[0049]

The luminous fluxlight beam having emanated the illumination aperture stop 10 arrives, through a relay lens 11, a bending mirror/folding mirror 12 and a relay lens 13, at a field stop 14. The field stop 14 (or a shaping device) is a device or member for restricting the illuminated field of view on the reticle 18.

[0050]

The present exposure apparatus is the scan type exposure apparatus, and the reticle 18 and the wafer 25 are scanned for the exposure in the Y direction. Therefore, the illumination field of view/illumination field on the reticle 18 is such a slit shape (or a rectangular shape) as is long in the X direction and short in the Y direction. Considering the reflection characteristics of a bending mirror/folding mirror 17, therefore, the field stop 14 is formed into such a rectangular shape as is long in the X direction and short in the Z direction. In order to adjust the width of the slit, it is further preferred that the stops defining the two ends of the field stop 14 in the Z direction can move in the Z direction. Like discussion applies to the X direction. The luminous fluxlight beam having passed through the field stop 14 irradiates the reticle 18 through relay lenses 15 and 16 and the bending mirror/folding mirror 17.

[0051]

The polarization control element 5 is an optical element for controlling the polarization state of the illumination light  $I_c$  to a predetermined state. In this predetermined state, the illumination light to irradiate the reticle 18 is a generally linear polarization, and its polarization direction (i.e., the direction of the electric-optical field vector of light) is aligned in the X direction, as shown. In the apparatus shown in Fig. 1, the polarization direction at the emanating position of the polarization control element 5 is also set in the X direction.

[0052]

The ordinary projecting optical system does not contain such a member (e.g., a wavelength plate/wave-plate or a polarization beam splitter) as changes the polarization direction of the illumination light (or the exposure light). Therefore, if when the polarization state of the illumination light to irradiate the reticle 18, as described above, is made parallel (or coincident with) to the X direction shown in the figure (i.e., the longitudinal direction of the field of view of the projecting optical system), the polarization state of the illumination light (or the exposure light) to irradiate the wafer through the mask and the projecting optical system is also generally parallel to the longitudinal direction of the field of view of the projecting optical system. Thus, the following description is made, premising that the polarization state of the illumination light to irradiate the reticle and the polarization state of the illumination light (or the focused light) to irradiate the wafer are equivalent.

[0053]

The emanation light (or the illumination light  $I_o$ ) of the

aforementioned excimer laser light source or the fluorine laser light source is a generally linear polarization light. In order to align the polarization direction of that linear polarization with the aforementioned predetermined direction, the 1/2 wavelength platewave-plate, which is made of an optical material such as quartz crystal (crystal of silicon dioxide) or magnesium fluoride crystal having a birefringence is inserted in the predetermined direction. Here, that polarization control element 5 need not be provided in the optically relative positional relation between the light source 1 and the illuminating optical system IL, in case the polarization direction of the illumination light  $I_c$  to be fed from the light source 1 to the illuminating optical system IL is aligned from the beginning with the aforementioned predetermined direction (or the X direction).

[0054]

In case the light source 1 emits a luminous fluxlight beam other than the linear polarization as in the lamp or the random polarization laser, the polarization filter or the polarization beam splitter for transmitting only the linear polarization in the aforementioned predetermined direction is used as the polarization control element 5.

[0055]

Here, the illumination light for irradiating the reticle 18 need not be a complete linear polarization, but the invention can exhibit its effect if the illumination light intensity is almost (e.g., about 80 % or more) a predetermined linear polarization. In case, therefore, the aforementioned polarization filter or polarization beam splitter is used, its polarization selection ratio is sufficient if it is at or over about 80 %. In case a fluorine laser with no narrowed band

is used as the light source, the illumination light  $I_c$  is a linear polarization of some extent, and contains a linear polarization perpendicular to the former. For the similar reasoning, the illumination light need not be linearly polarized any more.

[0056]

Fig. 2 is a top plan view showing one example of the reticle, which is being placed on the reticle stage 19. As shown in Fig. 2, patterns 32, 33 and 34 are drawn as major line patterns in a pattern area 30 of the reticle 18. These patterns 32, 33 and 34 are thin in line widths for transistor gates and strict in the width uniformity required, and require high-precision transfers so that they are formed along a predetermined direction. In the pattern area 30, there are formed other patterns (although not shown), which have relatively large widths such as wiring patterns formed at the end portions of the transistor gates, which are loose in the line width uniformity and which are formed along directions different from that of the patterns 32, 33 and 34.

[0057]

In this mode of embodiment, as shown in Fig. 2, the reticle 18 is so adsorbed and held on the reticle stage 19 that its major patterns 32, 33 and 34 extend generally in parallel with the X direction. Of the patterns to be transferred, specifically, the patterns 32, 33 and 34, which have the fine line width and important line width uniformity, are set in the X direction.

[0058]

In Fig. 2, an area 31, as shown by broken lines in the pattern area 30, corresponds to the exposure field of viewexposure field of the projecting optical system 24, and is so inscribed in a good image

rangeimage area 40 of the projecting optical system 24 that its center is aligned with the optical axis AX of the projecting optical system 24. However, the exposure field of viewexposure field of the projecting optical system 24 may be set eccentric with respect to the good image rangeimage area 40 of the projecting optical system 24. In this case, the center of the exposure field of viewexposure field is not aligned with the optical axis AX of the projecting optical system 24. The illumination light  $I_4$ , with which the reticle 18 is irradiated by the illuminating optical system IL, irradiates that area. The polarization state of the illumination light  $I_4$  has a major component of a linear polarization having a polarization direction in the X direction, as indicated by E in Fig. 2.

[0059]

At the exposure, the reticle 18 and the wafer 25 are scanned in the Y direction relative to each other while keeping their focusing relation. Therefore, the pattern (i.e., the pattern 34 and so on) not in the exposure field of viewexposure field 31, as shown in Fig. 2, is sequentially brought by that scan into the exposure field of viewexposure field 31 so that it is transferred to the wafer 25.

[0060]

Here is described one of the feature of the invention, that is, the relation between the pattern direction and the longer direction of the exposure field of viewexposure field or the polarization direction of the illumination light.

[0061]

Figs. 3 (A) to 3 (C) and Figs. 4 (A) to 4 (D) are diagrams for showing the relations between the pattern direction and the polarization direction. Fig. 3(A) and Fig. 4(A) show the case, in which a pattern

36 extending in the X direction is irradiated with a linear polarization  $I_{41}$  having the polarization direction  $E_1$  aligned with the X direction and a linear polarization  $I_{42}$  having the polarization direction  $E_2$  aligned with the Y direction.

[0062]

The illumination lights  $I_{41}$  and  $I_{42}$ , as diffracted by the pattern 36 extending in the Y direction, generate diffracted lights, respectively, in the +Y direction and the -Y direction. These diffracted lights are shown as a 0-th diffracted light D01, a -1st diffracted light DM1 and a +1st diffracted light DP1 in Fig. 3(A), and are shown as a 0-th diffracted light D02, a -1st diffracted light DM2 and a +1st diffracted light DP2 in Fig. 4(A). In the polarization state of each diffracted light, the polarization state of each illumination light  $I_{41}$  or  $I_{42}$  is stored. On an eye planepupil plane EP of the projecting optical system 24, the diffracted lights D01, DM1 and DP1 in Fig. 3(A) are linear polarizations in the X direction, and the diffracted lights D02, DM2 and DP2 in Fig. 4(A) are linear polarizations in the Y direction.

[0063]

The advancing directions of these diffracted lights (i.e., the diffracted lights diverged in the Y direction from the pattern (i.e., the pattern in the X direction) extending in the X direction, as described above) are diffracted again in the Y directions, after having passed through the eye planepupil plane EP, by the focusing action of the projecting optical system 24, and are condensed again on the wafer 25 so that interference fringes or the images of the pattern 36 are formed. The wafer 25 is irradiated (or illuminated) with those interference fringes so that the image is recorded on the

photoresist applied to the wafer surface.

[0064]

In addition to the refractions of the luminous fluxlight beam, the polarization direction is rotated in a direction perpendicular to the advancing direction of the luminous fluxlight beam. This rotation follows the physical law of the light, in which the direction of the electric field is always perpendicular to the advancing direction of the light.

[0065]

The diffracted lights DM2 and DP2 in Fig. 4(A) are linear polarizations in the Y direction on the eye planepupil plane EP, but their polarization direction change with the refractions of the diffracted lights DM2 and DP2. Fig. 4(B) is an enlarged diagram near the wafer 25 of Fig. 4(A). The polarization directions of the diffracted lights DM2 and DP2 are normal to the advancing directions of the individual luminous fluxlight esbeams and are offset from the Y direction. However, the advancing direction of the diffracted light D02 is the -Z direction so that the polarization direction is kept in the Y direction.

[0066]

The intensity distribution of the interference fringes (images) by such luminous fluxlight esbeams is the sum (the sum of X components is 0) of the square (or the energy) (the intensity distribution IM2 indicated by a solid line in Fig. 4(C)) of the sum of the Y direction components of the individual polarizations (or the electric field) and the square (or the energy) (the intensity distribution IM3 indicated by a broken line in Fig. 4(C)) of the sum of the Z direction components of the individual polarizations (or the electric field),

and becomes the intensity distribution IM4 of Fig. 4(D). At this time, however, the Z direction components of the electric fields of the diffracted lights DM2 and DP2 are inverted in their signs by the relations of the two polarization angles. As a result, the intensity distribution IM3 is offset in phase from the intensity distribution of the image formed by the Y direction component of the electric field thereby to lower the image contrast.

[0067]

As shown in Fig. 4(A), therefore, the pattern in the X direction is illuminated with the linear polarization of the Y direction. Then, the polarization directions of the illumination lights (or the individual diffracted lights) to irradiate the wafer are not parallel to each other. As a result, the contrast of the projected image drops so that it is not suitable for the transfer of a fine pattern.

[0068]

On the contrary, the polarization direction of the luminous fluxlight beam in the X direction on the eye plane/pupil plane EP, like the diffracted lights D01, DM1 and DP1 in Fig. 3(A), is kept in the X direction even if the advancing direction of the luminous fluxlight beam is refracted in the Y direction. As shown in Fig. 3(B), moreover, the wafer 25 is irradiated by the diffracted lights D01, DM1 and DP1 having their polarization directions arranged in the X direction, so that the interference fringes are formed. This interference fringe intensity distribution is determined from the square of the sum of the X direction components of the electric field (because the sum of the Y and Z components is 0), as shown as an intensity distribution IM1 in Fig. 3(C). This means that the contrast is high because the components have no inverted sign unlike the case of Fig. 4(A).

[0069]

The pattern of the X direction is so illuminated by the linear polarization having the polarization direction in the X direction that all the polarization directions of the illumination lights (or the individual diffracted lights) to irradiate the wafer may be parallel to the X direction, as shown in Fig. 3(A). Then, the projected image has such a high contrast as suits for the transfer of a fine pattern.

[0070]

Next, the relations between the pattern direction and the longer side direction of the exposure field of viewexposure field are described with reference to Fig. 5. Fig. 5 shows the exposure view fieldexposure field 31 of the projecting optical system 24. The exposure view fieldexposure field 31 is formed into a rectangular shape having a longer side along the X direction and a shorter side along the Y direction. Moreover, the exposure view fieldexposure field 31 frequently has its center C aligned with the optical axis AX of the projecting optical system 24, as has been described hereinbefore.

[0071]

The point image intensity distribution or the focusing characteristicimaging characteristics on a point 39 close to the end of the X direction on the exposure view fieldexposure field 31 are extended broadened (or blurred) in the radial direction and the concentric circle direction (i.e., in the X direction and in the Y direction for the point 39 in Fig. 5) of the projecting optical system 24 by the influences of the principle diffraction limits and the residual aberrations of the projecting optical system 24. As shown, point image intensity distributions 60 and 61 designate the X

direction section (or the radial direction section) and the Y direction section (or the concentric direction section) of the point image intensity distribution at the position of the point 39, respectively. Thus, it is general that the extending width of the point image distribution is made larger in the radial direction than in the concentric direction by the influences of the residual aberrations. The residual aberrations are various ones, of which the coma aberration and the magnification chromatic aberration are the major causes for making the extension of the point image distribution larger in the radial direction than that in the concentric direction.

[0072]

Of these aberrations, the coma aberration is difficult to remove completely, not only in the design but also in the manufacturing error. On the other hand, the magnification chromatic aberration can be eliminated by means of countermeasures, e.g., by using a suitable material (e.g., fluorite) for eliminating the chromatic aberration in a large quantity as the material of lenses constituting the projecting optical system 24, or by making the projecting optical system 24 into a cata-diopticcatadioptic system having concave mirrors assembled therein. However, either the countermeasure is followed by the problem of raising the cost for manufacturing the projecting optical system.

[0073]

Because of those aberrations left in the projecting optical system, in the periphery of the exposure view fieldexposure field 31, a pattern 37 parallel to the longer side of the exposure view fieldexposure field 31 is less subjected to the influences of the residual aberrations than a pattern 38 perpendicular to the longer

side direction of the exposure view fieldexposure field 31, so that the finer pattern can be transferred.

[0074]

In this mode of embodiment, of the patterns to be transferred, the pattern having a fine line width and a very important line width uniformity is directed in the X direction (i.e., the direction of the pattern 37), so that its transfer image is hardly subjected to the influences of the aforementioned aberration in the radial direction. Even if the same projecting optical system as that of the prior art is used, it is possible to resolve the finer pattern. Moreover, the illumination light to be emitted from the illuminating optical system IL is the linear polarization in the X direction or the most proper illumination for the pattern in the aforementioned X direction (i.e., the direction parallel to the longer side direction of the exposure view fieldexposure field 31), so that a finer pattern than that of the prior art can be resolved.

[0075]

If When the pattern to be exposed may be as fine as that of the prior art, the allowance of the residual aberration in the radial direction of the projecting optical system 24 used can be made looser than that of the projecting optical system of the prior art. Especially by relaxing the magnification aberration allowance, the cost for the projecting optical system can be lowered to provide an inexpensive projecting exposure apparatus.

[0076]

While leaving the chromatic aberration correction of the projecting optical system 24 as it is, moreover, the spectral width of the light source 1 can be loosened. In the case of the narrowed

laser, the loosening of the spectral width means the simplification of the laser band narrowing element, and can augment the laser output and elongate the lifetime of band-narrowed element, can improve the operating ability of the exposure apparatus, and can reduce the running cost for the band-narrowed element and for the exposure apparatus.

[0077]

Here in the aforementioned mode of embodiment, the reticle 18 is irradiated with the illumination light  $I_4$  having a main component in the polarization direction parallel to the X direction. Depending upon the pattern to be exposed, the polarization state of the illumination light to irradiate the reticle 18 may be preferably an unpolarization (or a natural light), a circular polarization or an elliptical polarization. In this mode of embodiment, therefore, the polarization control element 5 is desirably made removable or rotatable on the axis of the advancing direction of the illumination light.

[0078]

For example, the light source 1 is a laser light source for emitting a luminous fluxlight beam of a generally linear polarization, and a 1/2 wavelength platewave-plate is used as the polarization control element 5. In this case, as shown in Fig. 6, the polarization control element 5 is composed of two 1/4 wavelength platewave-plates 51 and 52. By the individual rotations on the axis of the advancing direction of the illumination light  $I_0$ , the luminous fluxlight beam  $I_1$  to be emitted can be made into a linear polarization or a circular polarization.

[0079]

Specifically, in case the exit light  $I_1$  is a linear polarization, it is sufficient to arrange the mutual longer axis direction of the 1/4 wavelength platewave-plates 51 and 52, and to set the direction of the exit light  $I_1$  intermediate between the polarization direction of the incident light  $I_0$  and the desired polarization direction of the exit light  $I_1$ . In order to make the exit light  $I_1$  into a circular polarization, it is sufficient to align the longer axis direction of the 1/4 wavelength platewave-plate 51 on the light source side with the polarization direction of the incident light  $I_0$  and to rotate the longer axis direction of the other 1/4 wavelength platewave-plate 52 by 45 degrees with respect to the aforementioned polarization direction.

[0080]

In case the light source 1 emits an unpolarized light, moreover, the polarization state of the illumination light  $I_4$  to irradiate the reticle 18 can be made variable by mounting and demounting a polarization filter or a polarization beam splitter as the polarization control element 5.

[0081]

Here, this mode of embodiment has been described on the step-and-scan type exposure apparatus, in which the pattern of the mask is transferred to the substrate while the mask and the substrate moving relative to each other, and in which the substrate is moved sequentially stepwise. However, the exposure may also be performed by the step-and-repeat type, in which the exposure view field exposure field having the longer side direction and the shorter side direction is used to transfer the pattern of the mask to the substrate while the mask and the substrate being stationary, and in which the substrate

is moved sequentially stepwise. This step-and-repeat type exposure apparatus is different from the step-and-scan type exposure apparatus in that the exposure is performed with the mask and the substrate being stationary from each other, and the remaining constitution can be identical to that of the step-and-scan type exposure apparatus. In case the invention is applied to the step-and-repeat type exposure apparatus, the polarization direction of the illumination light for the pattern of the mask is adjusted by the polarization control element 5, the field stop 14 is rotated on the optical axis of the illuminating optical system so that the longer side direction of the exposure field of the projecting optical system and the polarization direction of the illumination light can be parallel to each other. In case the polarization direction of the illumination light to be fed from the light source is identical from the beginning to a predetermined direction, it is sufficient to rotate the field stop 14 without providing the polarization control element.

[0082]

Here, in case the light source of the exposure apparatus is a vacuum ultraviolet ray such as the F<sub>2</sub> laser, the material for the transmission optical member of the used lens is exemplified by the so-called "modified quartz" such as fluoride crystal such as fluorite or fluorine added quartz having a high transmission to the vacuum ultraviolet ray. Moreover, the optical path has to be replaced, when used, by a rare or nitrogen gas having a high transmission to the vacuum ultraviolet ray.

[0083]

Here in the exposure apparatus using the F<sub>2</sub> laser as the light source, the material, which can be used as a lens to be adopted in

the illuminating optical system or the projecting optical system, is substantially limited to the fluorite by the transmittance. The fluorite is a crystal belonging to a cubic system, and has been thought in the prior art to cause no birefringence intrinsic to the crystal. In the 157 nm Symposium held (at Dana Point of California, USA) by International SEMTECH (Semiconductor Manufacturing Technology Institute), in May, 2001, it was published by NIST (National Institute of Standards and Technology) that the fluorite had the birefringence intrinsic to the crystal in the vacuum ultraviolet range.

[0084]

In the exposure apparatus using the random polarization illumination of the prior art, the birefringence of the lens material making the illuminating optical system has little influence on the final focusing performance imaging performance. In the prior art, therefore, no problem has been raised by the intrinsic birefringence of the fluorite lens arranged in the illuminating optical system.

[0085]

In case the mask pattern is illuminated with a linear polarization as in the invention, the rotation of the polarization direction accompanying the intrinsic birefringence of the fluorite lens in the illuminating optical system may raise a problem. Specifically, the intrinsic birefringence of the fluorite lens may act as the 1/2 wavelength plate wave-plate or the 1/4 wavelength plate wave-plate thereby to deviate the polarization direction of the illumination light to illuminate the mask pattern face, from a desired direction. In accordance with the place in the mask pattern plane, moreover, the polarization state of the illumination light may be different. Therefore, the following countermeasures are desired in

the exposure apparatus using the F<sub>2</sub> laser as the illuminating light source and adopting the crystal material such as the fluorite in the illuminating optical system.

[0086]

The following countermeasures are desired. Specifically, of fluorite lenses (of an S number) arranged in the illuminating optical system, a predetermined number (A) of fluorite lenses are arranged to have their optical axes aligned with the crystalline axis [111], and a predetermined number (a) of lenses, and the remaining number (A - a) of lenses are arranged to have their optical axes on the rotation center and to have their crystalline axes rotated by 60 degrees from each other. The remaining number B (= S - A) of lenses are arranged to have their optical axes aligned with the crystalline axis [100], and a predetermined number (b) lenses, and the remaining number (B - b) of lenses are arranged to have their optical axes on the rotation center and to have their crystalline axes rotated by 45 degrees from each other.

[0087]

Fig. 7 exemplifies the case, in which the aforementioned countermeasures are applied to the four lenses in the illuminating optical system. All four lenses L1, L2, L3 and L4, as arrayed along the optical axis LAX of the illuminating optical system, are made of fluorite. Of these, the lenses L1 and L2 have their optical axes (aligned with the optical axis LAX of the illuminating optical system) aligned with the [100] axis of the fluorite crystal, and the crystalline axes (i.e., the [010] axis and the [001] axis) of the fluorite crystal in the in-plane direction of the two lenses (i.e., in the plane normal to the optical axis LAX) are rotated by 45 degrees,

as shown.

[0088]

On the other hand, the lenses L3 and L4 have their optical axes (aligned with the optical axis LAX of the illuminating optical system) aligned with the [111] axis of the fluorite crystal, and the crystalline axes (i.e., the [0-11] axis, the [-110] axis and the [-101] axis) of the fluorite crystal in the in-plane direction of the two lenses (i.e., in the plane normal to the optical axis LAX) are rotated by 60 degrees, as shown.

[0089]

By applying those countermeasures to the illuminating optical system, the polarization state of the illumination light on the mask pattern plane can be made into the desired linear polarization, so that the effects of the invention can be sufficiently exhibited.

[0090]

In case the fluorite is adopted for the lenses in the projecting optical system, the influences for the intrinsic birefringence to give the focusing performance imaging performance of the projecting optical system can be solved by optimizing what crystalline axis the optical axes of each fluorite lens used is aligned with, or what angle each lens is rotated and arranged by on the optical axis, as reported by our report SPIE (International Society for Optical Engineering Microlithography Symposium) in March, 2002.

[0091]

Here, the foregoing mode of embodiment has been described with the premise that the projecting optical system contains none of the member (e.g., the wavelength plate wave-plate or the polarization beam splitter) for changing the polarization direction of the illumination

light (or the exposure light). In a kind of cata-diopticcatadioptic system, however, there is contained a polarization state changing member such as a wavelength platewave-plate or a polarization beam splitter. In this case, the exposure view fieldexposure field of the projecting optical system frequently has a slit shape. However, the polarization state of the illumination light to irradiate the reticle and the polarization state of the illumination light (or the exposure light) to irradiate the wafer side may be changed by the aforementioned polarization state changing member, and their relations between the longitudinal direction and the polarization direction of the exposure view fieldexposure field may not coincide.

[0092]

In case the invention is applied to the exposure apparatus having such projecting optical system, the polarization state of the illumination light to irradiate the reticle is desirably set such that the polarization state of the illumination light (or the exposure light) to irradiate the wafer plane finally through the projecting optical system may be parallel to the longitudinal direction of the exposure view fieldexposure field slit in the wafer plane. Even if when the illumination light on the reticle side is set parallel to the longitudinal direction of the exposure view fieldexposure field slit on the reticle side, the polarization state of the illumination light (or the exposure light) to enter the wafer comes into the undesired state so that the effect of the invention cannot be acquired, when the polarization state by the projecting optical system is changed by the aforementioned polarization state changing member.

[0093]

In the foregoing mode of embodiment, the gas (e.g., the air or

the gas having little absorption to the ultraviolet ray) exists in the space between the projecting optical system and the wafer. However, the invention should not be limited to that existence but may be modified such that the space between the projecting optical system and the wafer is filled with a liquid. This structure is the liquid-immersed optical systemliquid immersion optical system, in which the wavelength of the illumination light (or the exposure light) to irradiate the wafer is reduced by a submultiple of the refractive index of that liquid, thereby to realize a higher improvement of the resolution of the exposure apparatus.

[0094]

In the liquid immersed optical systemliquid immersion optical system, the sinusoidal value of the angle made between the 0-th light and the 1st light of the illumination light (or the exposure light) in the liquid at the time of exposing the pattern of the common pitch in the common wavelength is reduced by a submultiple of the refractive index of that liquid, as compared with the case of the optical system of not the liquid immersed immersion type. In other words, the reduction means that even the projecting optical system of a similar constitution can enlarge increase its numerical aperture by the refractive index of the liquid, and this is a main cause for improving the resolution.

[0095]

In the photoresist for forming a latent image of the pattern actually, however, the refractive index of the photoresist is identical even for the liquid-immersed optical systemliquid immersion optical system and for the ordinary optical system of not the liquid immersed type. Therefore, the sinusoidal value of the angle made

between the 0-th light and the 1st light of the illumination light (or the exposure light) at the time of exposing the pattern of the common pitch in the common wavelength is identical for the two optical systems. In the liquid immersed optical systemliquid immersion optical system to be exposed to a finer (fine pitch) pattern than that of the ordinary optical system, therefore, the deviations in the polarization direction between the diffracted lights (or the exposure lights) of the individual orders in the resist are so large that the image contrast is more lowered, if when the polarization state of the illumination light (or the exposure light) to irradiate the resist is undesirable. By applying the invention to the liquid immersed projecting optical system, therefore, a higher effect can be obtained than that of the case, in which the invention is applied to the projecting optical system of not the liquid immersed type of the prior art.

[0096]

Next, in the C-MOS-LSI or the present mainstream of the semiconductor integrated circuit, an electronic device is generally formed on the surface of a silicon crystal, the <100> plane of which extends in the wafer surface. In the C-MOS-LSI, the n-MOS transistor and the p-MOS transistor form a transistor pair on the surface of the silicon wafer. If the wafer used has the surface of the <100> plane of the crystal, as described above, there arises a problem that the mobility of the holes (or positive holes) of the p-MOS transistor is low.

[0097]

In the silicon wafer having its surface extending in the <111> plane of the crystal (or the wafer having the [111] crystalline axis

normal to the surface), on the other hand, the mobilities of electrons and holes in the axial azimuth [110] in the <111> plane and in the equivalent azimuth in the <111> plane are so high that the C-MOS-LSI can act at higher speeds. Here, the equivalent azimuth includes the azimuth, in which the orders of the individual indexes are interchanged, and the azimuth, in which at least one index sign is inverted. Of these, the azimuths existing in the aforementioned <111> plane are the [-110] axial azimuth, the [10-1] axial azimuth, the [-101] axial azimuth, the [01-1] axial azimuth and the [0-11] axial azimuth.

[0098]

Here, either the [1-10] axis or an equivalent axis has three azimuths individually intersecting at an angle of 120 degrees in the <111> plane of the crystal. Therefore, if the longitudinal direction of the gate pattern is formed in parallel with the direction in the <111> plane normal to that azimuth, i.e., the [11-2] crystalline axis or the axial equivalent to the former and existing in the <111> plane (e.g., the crystalline axis [1-21] and the crystalline axis [2-1-1] crystalline axis), the moving direction of the electrons and holes in the MOS transistor containing that gate can be aligned with the [1-10] axial azimuth or the [-110] axial azimuth of a higher mobility, thereby to acquire a higher speed of the actions of the C-MOS-LSI.

[0099]

As a matter of fact, for a reticle of a square contour, the drawing precision of the fine pattern not in parallel with the side (i.e., the uniformity of the pattern width) is inferior to the parallel fine pattern. It is, therefore, preferred that the pattern azimuths on the reticle are arranged in the direction of the sides of the square

of the reticle contour. If, however, either the [1-10] axis of three azimuths individually intersecting at an angle of 120 degrees or one equivalent axis is aligned with one of the reticle contour in the aforementioned <111> plane of the crystal, the remaining two azimuths are undesirable ones for the precision in the formation of the reticle pattern. In case, therefore, a higher speed C-MOS-LSI is realized by using the wafer having the [111] axis as the crystalline axis normal to the surface, it is necessary that the longitudinal directions of the substantially usable gate patterns be arranged in one direction (i.e., the [-112] axis and any of the equivalent axial directions). This necessity is examined in the following.

[0100]

Fig. 8(A) is a diagram showing the azimuth of the silicon crystal in the wafer surface of the silicon wafer, in which the crystalline axis normal to the surface is the [111] axis. In short, the wafer surface is included in the <111> plane of the silicon crystal. As shown, the [111] axis is normal to the sheet face (i.e., normal to the wafer surface). In the wafer plane, the crystalline axes (i.e., the [0-11] axis, the [-110] axis and the [-101] axis), which are equivalent to the [110] axis of the azimuth having the high electron and hole mobilities, are arranged at an angular interval of 120 degrees. In Fig. 8(A), the rotating direction of the wafer is set in such a predetermined direction as to align the [-110] axis and the shown Y-axis with each other.

[0101]

In order to accelerate the action speed of the MOS transistor, it is desired that the moving direction of the electrons and holes in the transistor is aligned with either the aforementioned [110] axis

or an equivalent axial direction. It is, therefore, desired that the longitudinal direction of the gate pattern is oriented to intersect the [110] axis or an equivalent axial direction at a right angle, as indicated by gate patterns G1, G2 and G3 in Fig. 8(A). In the case of Fig. 8(A), therefore, the gate patterns are preferably arranged in the three directions having the relatively rotational relations of 120 degrees of the gate G1, in which the [11-2] axial direction (aligned with the X-axis of the drawing) perpendicular to the [-110] axial direction in the <111> plane is longitudinal, the gate G2, in which the [1-21] axial direction perpendicular to the [-101] axial direction in the <111> plane is longitudinal, and the gate G3, in which the [2-1-1] axial direction perpendicular to the [0-11] axial direction in the <111> plane is longitudinal.

[0102]

Here in Fig. 8(A), a rectangular area EXF, as enclosed by broken lines, is the exposure view fieldexposure field area of the projecting optical system of the exposure apparatus of this embodiment, and its longer side direction is aligned with the X direction, i.e., the longitudinal direction of the gate G1 and the [11-2] axial direction of the silicon crystal.

[0103]

Fig. 8(B) is a top plan view of the reticle to be used in the exposure apparatus of the embodiment. In a pattern area PA, a master of a pattern to be transferred is drawn. This drawing precision (or the line width precision and the drawing position precision) is so set by the precision of the EB (electron beam) drawing machine for drawing the pattern that the precision is high, in case the pattern is parallel (i.e., in the X direction and in the Y direction) to the

outer side of the reticle (or square), but low in case the pattern is inclined.

[0104]

In order to form the highly precise pattern on the wafer, therefore, it is preferred that the longitudinal direction of the pattern on the reticle is set in the X direction and the Y direction parallel to the outer sides of the reticle, as indicated by patterns P1 and P2. At present, the patterns of such directions are generally used.

[0105]

In case the wafer having the surface of the <111> plane is used, as shown in Fig. 8(A), the preferred gate pattern direction is limited to the three directions of every 120 degrees. Therefore, the longitudinal directions of the gate patterns, which satisfy both the restriction of the drawing precision of the reticle pattern and the restriction from the transistor action speed, are restricted to only the direction of the gate pattern G1 parallel to the X direction in Fig. 8(A).

[0106]

When the semiconductor device and another electronic device are manufactured by using the projecting exposure apparatus according to the mode of embodiment thus far described, an electronic device capable of acting at a higher speed can be manufactured by arranging the pattern directivity, which is given a high resolution by the projecting exposure apparatus of the mode of embodiment, and the direction of the pattern which is determined from the viewpoints of the transistor action speed and the reticle drawing precision.

[0107]

Specifically, the silicon wafer having its surface included in the <111> plane of the crystal (that is, having its surface normal to the [111] axis) is used. The silicon wafer is so placed on the wafer stage (26) of the projecting exposure apparatus that its [-110] axis may be aligned with the shorter side direction of the exposure view fieldexposure field of the projecting optical system (that is, its [11-2] axis may be aligned with the longer side direction of the exposure view fieldexposure field of the projecting optical system). The silicon wafer is so arranged that the longitudinal direction of the fine gate pattern on the reticle is aligned with the longer side direction of the exposure view fieldexposure field of the projecting optical system, and is irradiated with the generally linear polarization of the polarization direction (or the electric field direction), in which the polarization direction of the focusing luminous fluxlight beam leading to the wafer may be substantially aligned with the longer side direction of the exposure view fieldexposure field of the projecting optical system.

[0108]

As a result, the gate directed suitably for the high-speed actions on the silicon crystal can be exposed and transferred more precisely with a finer line width thereby to improve the performance of the electronic device drastically.

[0109]

For the index of the crystalline axis in the foregoing description, the azimuth vertically normal to the wafer surface is set to the [111] axial direction, on which the indexes of other axes are determined. The substance is not changed in the least, even if the azimuths of other axes are expressed by using that axis as the

axis equivalent to the [111] axis (i.e., the axis having the index of the rearranged order and the axis having the index partially inverted) such as the [11-1] axis or the [1-11] axis. Therefore, even the [0-11] axis, the [-110] axis and the [-101] axis of the silicon wafer surface, as shown in Fig. 8(A), may be other axes, if they are equivalent to the [110] axis. Moreover, it is needless to say that the axis to be aligned with the longer side direction of the exposure view fieldexposure field of the projecting optical system may be any crystalline axis, so long as it is perpendicular to the axis equivalent to the [110] axis existing in the plane equivalent to the <111> plane that is, equivalent to the [112] axis.

#### [0110]

In the scanning type exposure apparatus of this embodiment, the projecting optical system has its exposure view fieldexposure field substantially aligned in its longer side direction with the polarization direction of the illumination light. As a result, the exposure apparatus is excellent in resolution and contrast for the pattern having the longitudinal direction in the direction parallel to the longer side direction of the exposure view fieldexposure field. Therefore, the exposure apparatus is especially suited for forming the gate pattern arrayed in one direction, on the silicon wafer, in which the crystalline axis normal to the surface is the [111] axis. In addition, the crystalline azimuth of the silicon wafer, in which the crystalline axis normal to the surface is the [111] axis, is so set that the exposure view fieldexposure field longer side direction and one of the [11-2] axis and the axial azimuth in the equivalent <111> plane may be parallel. As a result, the preferable condition can be satisfied to manufacture the electronic device capable of

acting at the high speed.

[0111]

Here, the alignment between the longer side direction of the exposure view field/exposure field and the predetermined crystalline axis of the wafer is to form the notch, the orientation flat, the identification mark or the like in a predetermined direction of the wafer peripheral edge. This alignment can be easily made by a method similar to the pre-alignment made by the ordinary exposure apparatus.

[0112]

Moreover, the crystalline axis of the wafer need not be made such that the direction normal to the surface and the [111] axis are completely aligned, but the effects of the invention can be sufficiently exhibited if the angular alignment is within bout 5 degrees.

[0113]

When a wafer (as will also called the "[110] wafer", in which a crystalline axis normal to the surface is the [110] axis, is used, the action speed of the transistor on the wafer can be better improved than the case, in which the wafer (as will also be called the "[100] wafer) used in the conventional C-MOS-LSI and having the crystalline axis [100] axis normal to the surface is used, or in which the wafer (as will also be called the "[111] wafer) having the crystalline axis [111] axis normal to the surface is used.

[0114]

In this case, however, the action speed can be improved only in case the moving direction of the electrons or holes in the transistor is generally aligned, as shown in Fig. 9(A), with the axial direction equivalent to the [-110] axis of the surface of the wafer, in which

the crystalline axis normal to the surface is the [110] axis, (that is, the wafer having the surface as the <110> plane of the crystal).  
[0115]

Therefore, the longitudinal direction of the transistor gate pattern to be formed on the wafer should be limited in the X direction in Fig. 9(A), according to a shown pattern G4. In the crystalline axis directions in the wafer shown in Fig. 9(A), the [-110] axis or its equivalent axial direction is aligned with the Y direction, as shown, and the [00-1] axis or its equivalent axial direction is aligned with the X direction, as shown. Moreover, the X direction is aligned with the longer side direction of the view field EXF of the projecting optical system of the exposure apparatus of this mode of embodiment, and with the polarization direction of the main component of the polarization (or the linear polarization) of the illumination light of the exposure apparatus of the mode of embodiment.

[0116]

Thus, with respect to the exposure apparatus of this mode of embodiment, the [110] wafer is arranged in the aforementioned rotational direction (i.e., the rotational direction, in which the [001] axis of the silicon crystal or the equivalent axis is parallel to the polarization direction of the main component of the polarization (or the linear polarization) of the illumination light). As a result, it is possible to transfer more finely and highly precisely the gate pattern of the transistor, in which the moving direction of the electrons and holes is equivalent to either the direction [-110] of the large electron and hole mobilities on the [110] wafer or the equivalent direction (that is, the transistor, in which the longitudinal direction of the gate pattern perpendicular to the moving

direction of the electrons and holes is parallel to the [001] of the silicon crystal or the equivalent axis).

[0117]

As a result, it is possible to manufacture the electronic device (C-MOS-LSI) of a higher speed than that of the prior art.

[0118]

Fig. 9(B) is a top plan view of the reticle to be used in this case. The master of a pattern to be transferred is drawn in the pattern area PA. In case the wafer having the surface of the <110> plane is used, as shown in Fig. 9(A), the preferred gate direction is limited to one direction so that the longitudinal direction of the pattern master is also limited to the direction of the gate pattern G4 parallel to the X direction in Fig. 9(A).

[0119]

Here, the semiconductor wafer (or the silicon wafer) may also be the distorted silicon, which is recently proposed. The distorted silicon is the wafer surface portion, in which the C-MOS-LSI is formed, and its semiconductor crystalline structure has an intentional distortion (or an extension/shrinkage).

[0120]

On the surface of a silicon wafer, for example, a silicon-germanium crystal having a larger lattice constant than that of a silicon crystal is formed as a thin film, and a silicon crystal is formed again as a thin film on the former thin film. In this case, the uppermost (or surface) silicon layer is tensed by the influence of the lattice constant of the silicon-germanium crystal of the lower layer so that its crystal lattice is extended/shrunken and distorted. As a result, the mobilities of the electrons and holes in the uppermost

(or surface) silicon layer can be raised to improve the action speed of the transistor.

[0121]

Generally speaking, that distortion occurs generally isotropically in the wafer plane, but can also be limited to one predetermined direction by a predetermined process. If the aforementioned silicon-germanium film and the upper silicon film are formed on the [110] plane of the silicon wafer, for example, the distortion direction is also limited substantially to one direction.

[0122]

Thus, in the wafer having its surface distortion limited to one predetermined direction, the electron or hole mobilities in the surface become the maximum in the predetermined one direction or in the perpendicular direction. By aligning the transistor forming direction with the direction to maximize the electron or hole mobilities in that transistor, therefore, the action speed of the transistor can be drastically improved.

[0123]

In this case, it is desired that the longitudinal direction of the gate pattern of the transistor is perpendicular to the direction, in which the electron or hole mobilities take the maximum, and that the longitudinal directions of the gate patterns of all the transistors on the silicon wafer are arranged into one direction.

[0124]

In the exposure apparatus of this mode of embodiment, the wafer is exposed to the illumination light containing much linear polarization parallel to the longer side direction of the rectangular exposure view field/exposure field of the projecting optical system.

At the time of exposing the aforementioned anisotropic distorted silicon wafer, therefore, the gate pattern of the transistor is set parallel to the longer side direction (or the second direction) of the exposure view field/exposure field of the projecting optical system, so that the highly precise and fine gate pattern having a better line width controllability than that of the exposure apparatus and the exposure method of the prior art can be transferred. Specifically, that direction of the aforementioned anisotropically distorted silicon wafer, in which the mobility of at least either the electrons or the holes takes the maximum, and the polarization direction (or the direction of the electric field) of the illumination light of the generally linear polarization fed by the exposure apparatus, are made perpendicular to each other for the exposure. As a result, the line width of the gate pattern in the electronic device to be manufactured and the uniformity of the line width can be improved better than the prior art so that an electronic device of a higher speed than that of the prior art can be manufactured additionally by adopting the distorted silicon wafer.

[0125]

The foregoing mode of embodiment has been described assuming the C-MOS-LSI as the electronic device. However, the invention should not be limited to that C-MOS-LSI but can be naturally adapted for the manufacture of the n-MOS, the p-MOS or another device.

[0126]

On the other hand, the exposure apparatus should not be limited to the application for manufacturing the semiconductor device but can be widely applied to a liquid crystal exposure apparatus for exposing and transferring the liquid crystal display element pattern to a

rectangular glass plate, or an exposure apparatus for manufacturing a thin film magnetic head. Another application is made to an exposure apparatus for manufacturing a micro machine, a DNA chip or a mask.

[0127]

The exposure apparatus of this mode of embodiment can be manufactured: by assembling an illuminating optical system and a projecting optical system composed of plural lenses and so on, into the exposure apparatus body, and assembling them optically; by mounting a reticle stage and a wafer stage composed of numerous mechanical parts, on the exposure apparatus body, and wiring and piping them; and by performing the overall adjustments (e.g., the electric adjustments and the action confirmations). Here, it is desired that the exposure apparatus is manufactured in a clean room having the temperature and the cleanliness controlled.

[0128]

The semiconductor device is manufactured through: the step of performing the function-performance designs of the device generally; the step of creating a reticle based on the designing step; the step of creating a wafer from a silicon material; the step of exposing and transferring the pattern of the reticle to the wafer having a resist applied thereto, by an exposure apparatus, and developing the pattern; the device assembling step (including the dicing step, the bonding step and the packaging step); and the testing step.

[0129]

Here, it is needless to say that the invention should not be limited to the mode of embodiment thus far described but could be modified in various manners within the scope of the invention.

[0130]

## [Advantage of the Invention]

According to the invention, as has been described hereinbefore, a substrate is exposed to an illumination light (or exposure light) incident on the substrate, while being irradiated with the illumination light which is mainly composed of a linear polarization in the polarization direction parallel to the direction perpendicular to the moving direction of the mask and the substrate. As a result, the contrast of the projected image on the line pattern extending in the direction along the direction perpendicular to that moving direction can be raised to transfer the fine pattern highly precisely.

[0131]

If When the pattern to be exposed and transferred may be as fine as that of the prior art, the allowance of the residual aberration in the radiation direction of the projecting optical system can be loosened more than that of the projecting optical system of the prior art. By relaxing the magnification aberration allowance, the cost for the projecting optical system can be lowered to provide a less expensive projecting exposure apparatus according to the invention.

[0132]

Moreover, the spectrum width of the light source can also be relaxed while leaving the chromatic aberration correction of the projecting optical system. In the case of the band-narrowed laser, the relaxation of the spectrum width means the simplification of the band-narrowed laser element thereby to raise the laser output, elongate the lifetime of the band-narrowed element and improve the throughput of the exposure apparatus. As a result, it is possible to reduce the running cost of the band-narrowed element and accordingly the running cost of the exposure apparatus.

[0133]

Moreover, the exposure is performed by using the illumination light which is mainly composed of the linear polarization of the polarization direction parallel to the direction normal to the moving direction of the mask and the substrate, and the direction of the pattern such as the gate pattern to be exposed and transferred onto the substrate is optimized in relation to the crystalline axis of the substrate, so that the device manufactured can act at the high speed.

[Brief Description of the Drawings]

[Fig. 1] A diagram showing a schematic constitution of an exposure apparatus according to a mode of embodiment of the invention.

[Fig. 2] A top plan view showing a reticle of a mode of embodiment of the invention.

[Fig. 3] Diagrams showing the relations between the pattern direction and the polarization direction of the mode of embodiment of the invention, and showing the case, in which the pattern direction and the polarization direction are parallel to each other.

[Fig. 4] Diagrams showing the relations between the pattern direction and the polarization direction of the mode of embodiment of the invention, and showing the case, in which the pattern direction and the polarization direction are perpendicular to each other.

[Fig. 5] A diagram showing an exposure field of viewexposure field of the mode of embodiment of the invention.

[Fig. 6] A diagram showing one example of the constitution of a polarization control element of the mode of embodiment of the invention.

[Fig. 7] A diagram showing a preferred lens arrangement of the case, in which fluorite lenses are used in an illuminating optical system

of the mode of embodiment of the invention.

[Fig. 8] Diagrams showing the relations between a wafer crystal axis and a pattern forming direction of a mode of embodiment of the invention, (A) a top plan view of a wafer, and (B) a top plan view of a reticle.

[Fig. 9] Diagrams showing the relations between a wafer crystal axis and a pattern forming direction of a mode of embodiment of the invention, (A) a top plan view of a wafer, and (B) a top plan view of a reticle.

[Description of Reference Numerals and Signs]

1 - - - Light Source

5 - - - Polarization Control Element  
(Adjusting Device)

14 - - - Field Stop (Shaping Device)

18 - - - Reticle (Mask)

19 - - - Reticle Stage (Stage Device)

24 - - - Projecting Optical System

25 - - - Wafer (Sensitive Substrate)

26 - - - Wafer Stage (Stage Device)

31 - - - Exposure Field of ViewExposure field

32 to 34 - - - Major Pattern

I<sub>0</sub> to I<sub>4</sub> - - - Illumination Light

## 【特許請求の範囲】

## 【請求項 1】

マスクに形成されたパターンの像を基板上に転写する走査型の露光装置において、  
前記マスクと前記基板とを第1方向に沿って相対的に移動するステージ装置と、  
前記マスクを照明する照明光学系と、  
前記マスクのパターンを前記基板上に投影する投影光学系とを備えるとともに、  
前記照明光学系は、前記投影光学系を介して前記基板上に照射される照明光の偏光状態を  
前記第1方向に直交する第2方向に平行な偏光方向の直線偏光を主成分とするように、  
前記マスクを照光することを特徴とする露光装置。

## 【請求項 2】

前記基板上に照射される照明光はその偏光度が80%以上であることを特徴とする請求項  
1に記載の露光装置。

## 【請求項 3】

前記照明光学系は、前記基板に照射される照明光の断面形状を前記第2方向に長手方向を  
有するスリット状に整形することを特徴とする請求項1または2に記載  
の露光装置。

## 【請求項 4】

前記ステージ装置は、前記マスクに形成されたパターンのうち、ラインパターンの長手方  
向と前記第2方向とが実質的に平行となるように、前記マスクを保持することを特徴とす  
る請求項1～3のいずれか一項に記載の露光装置。

## 【請求項 5】

前記照明光学系は、光源からの光を前記第2方向に平行な偏光方向の直線偏光を主成分と  
する照明光に調整する調整装置を有することを特徴とする請求項1～4のいずれか一項に  
記載の露光装置。

## 【請求項 6】

前記照明光学系は、前記投影光学系を介して前記基板に照射される照明光を、前記第2方  
向に平行な偏光方向の直線偏光を主成分とする照明光とするか、自然光又は円偏光あるいは  
は椭円偏光とするかを選択的に切り替える切り替え機構を有することを特徴とする請求項  
1～5のいずれか一項に記載の露光装置。

## 【請求項 7】

照明光のもとで、マスクに形成されたパターンの像を投影光学系を介して基板上に転写す  
る露光装置において、  
前記基板上の前記投影光学系の露光视野を、長手方向を有する形状に整形する整形装置と  
前記照明光の偏光方向と前記整形装置との少なくとも一方を調整し、前記基板上の露光视  
野の長手方向と前記照明光の偏光方向とを互いに平行にする調整装置とを有することを特  
徴とする露光装置。

## 【請求項 8】

前記マスクを前記照明光で照光する照明光学系を有し、  
前記整形装置は、前記照明光学系に設けられることを特徴とする請求項7に記載の露光装  
置。

## 【請求項 9】

前記整形装置は、光源からの光を前記基板上の露光视野の長手方向に平行な偏光方向を主  
成分とする照明光に調整することを特徴とする請求項1～10

前記マスクと前記基板とを第1方向に沿って相対的に移動するステージ装置を有し、  
前記露光视野の長手方向は、前記第1方向に直交する方向であることを特徴とする請求項  
7～9のいずれか一項に記載の露光装置。

## 【請求項 11】

前記照明光学系は、アシカ物語で形成される複数の光学要素を有し、

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(12) 公開特許公報(A)

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(54) [発明の名稱] 露光装置及び露光方法並びにデバイス製造方法

(57) [要約]

【課題】 ベンチマークの高精度転写を実現する。

【解決手段】 光源1及び偏光光波板5を含む照明光学系11により、X方向に平行な偏光方向の直線偏光を主成分とし、該X方向に見手方向を有するスリット状の照明光4が、Y方向に延びる主要なラインパターンを含むパターンが形成されたレチクル18に照射される。レチクルステージ19上に保持されたレチクル18と、ウェーハステージ26上に保持されたウェーハ25は、ステージ19、25によりY方向に沿って移動され、レチクル18のパターンの投影光学系24による投影像がウエハ25上に依次転写される。

【図版図】 図1



## 30

前記照明光学系は、前記投影光学系を介して前記基板に照射される照明光を、前記第2方  
向に平行な偏光方向の直線偏光を主成分とする照明光とするか、自然光又は円偏光あるいは  
は椭円偏光とするかを選択的に切り替え機構を有することを特徴とする請求項  
1～5のいずれか一項に記載の露光装置。

## 【請求項 7】

照明光のもとで、マスクに形成されたパターンの像を投影光学系を介して基板上に転写す  
る露光装置において、  
前記基板上の前記投影光学系の露光视野を、長手方向を有する形状に整形する整形装置と  
前記照明光の偏光方向と前記整形装置との少なくとも一方を調整し、前記基板上の露光视  
野の長手方向と前記照明光の偏光方向とを互いに平行にする調整装置とを有することを特  
徴とする露光装置。

## 【請求項 8】

前記マスクを前記照明光で照光する照明光学系を有し、  
前記整形装置は、前記照明光学系に設けられることを特徴とする請求項7に記載の露光装  
置。

## 【請求項 9】

前記整形装置は、光源からの光を前記基板上の露光视野の長手方向に平行な偏光方向を主  
成分とする照明光に調整することを特徴とする請求項1～10

前記マスクと前記基板とを第1方向に沿って相対的に移動するステージ装置を有し、  
前記露光视野の長手方向は、前記第1方向に直交する方向であることを特徴とする請求項  
7～9のいずれか一項に記載の露光装置。

## 【請求項 11】

前記照明光学系は、アシカ物語で形成される複数の光学要素を有し、

## 50

前記複数の光学素子は、前記照明光学系の光軸方向に関して、一部の光学素子の結晶軸の種類と、他の光学素子の結晶軸の種類とが異なることを特徴とする請求項 1～10 のいずれか一項に記載の露光装置。

#### 【請求項 12】

前記一部の光学素子における前記照明光学系の光軸方向に直交する結晶軸に対して、前記他の光学素子における前記照明光学系の光軸方向に直交する結晶軸が、前記照明光学系の光軸を中心軸として相互に回転して配置されていることを特徴とする請求項 11 に記載の露光装置。

#### 【請求項 13】

パターンが形成されたマスクと基板とを第 1 方向上に沿って相対的に移動させつつ、膜マスクのバターンを投影光学系を介して該基板上に転写する露光方法であって、前記基板上に照射される照明光は、前記第 1 方向上に直交する第 2 方向上に長手方向を有するシリット状の照明光であるとともに、前記第 2 の方向に平行な直線露光を主成分とする照明があることを特徴とする露光方法。

#### 【請求項 14】

前記マスクに形成された前記バターンのうち、ラインバターンの長手方向と前記第 2 方向とが実質的に平行となるように設定した状態で露光することを特徴とする請求項 13 に記載の露光方法。

#### 【請求項 15】

前記照明光はその屈光度が 80 %以上であることを特徴とする請求項 13 又は 14 に記載の露光方法。

照明のもとで、マスクに形成されたバターンの像を投影光学系を介して基板上に転写する露光方法。

#### 【請求項 16】

前記基板上の前記投影光学系の露光視野を、長手方向を有する形狀に整形し、前記基板上に照射される照明光の屈光方向を前記基板上の露光視野の長手方向と平行にして、前記マスクのバターンの像を前記基板上に転写することを特徴とする露光方法。

#### 【請求項 17】

前記マスクに形成された前記バターンのうち、ラインバターンの長手方向と前記露光視野の長手方向とが実質的に平行となるように設定した状態で露光することを特徴とする請求項 16 に記載の露光方法。

#### 【請求項 18】

前記マスクと前記基板とを第 1 方向上に沿って相対的に移動させた状態で露光する際に、前記露光視野の長手方向は、前記第 1 方向上に直交することを特徴とする請求項 16 又は 17 に記載の露光方法。

#### 【請求項 19】

請求項 1～12 のいずれか一項に記載の露光装置を用いたデバイス製造方法であって、前記基板として、その表面に垂直な方向が「111」結晶軸にほぼ一致するシリコン結晶基板を用い、前記「111」結晶軸と直交する「11-2」結晶軸またはこれと等価な結晶軸を、前記第 2 方向上又は前記露光視野の長手方向に一致させた状態で前記照明光で前記基板を露光することを特徴とするデバイスの製造方法。

#### 【請求項 20】

前記マスクに形成されたガートバターンを、前記「11-2」結晶軸、またはこれと等価な結晶軸と実質的に平行となるように、前記基板上に露光することを特徴とする請求項 19 に記載のデバイス製造方法。

#### 【請求項 21】

請求項 1～12 のいずれか一項に記載の露光装置を用いたデバイス製造方法であって、前記基板として、その表面に垂直な方向が「110」結晶軸にほぼ一致するシリコン結晶基板を用い、前記「110」結晶軸と直交する「00-1」結晶軸又はこれと等価な結晶軸を、前記第 1 方向上又は前記露光視野の長手方向に一致させた状態で前記照明光で前記基板を露光することを特徴とするデバイス製造方法。

#### 【発明の詳細な説明】

【0001】

2 方向又は前記露光視野の長手方向に一致させた状態で前記照明光で前記基板を露光することを特徴とするデバイス製造方法。

#### 【請求項 22】

前記マスクに形成されたガートバターンを、前記「00-1」結晶軸又はこれと等価な結晶軸と実質的に平行となるように、前記基板上に露光することを特徴とする請求項 21 に記載のデバイス製造方法。

#### 【請求項 23】

請求項 1～12 のいずれか一項に記載の露光装置を用いたデバイス製造方法であって、前記基板として、その表面層の半導体結晶構造が少なくとも所定の 1 方向上に至んだ半導体ウエハを用い、前記表面層中の電子又はホールの少なくとも一方の移動度が最大となる方向を前記第 1 方向又は前記露光視野の長手方向に一致させた状態で前記基板を露光することを特徴とするデバイス製造方法。

#### 【請求項 24】

前記表面層はシリコン結晶層であることを特徴とする請求項 23 に記載のデバイス製造方法。

【請求項 25】

請求項 1 ～ 18 のいずれか一項に記載の露光方法を用いたデバイス製造方法であって、前記基板として、その表面に垂直な方向が「111」結晶軸にほぼ一致するシリコン結晶基板を用い、前記第 2 方向又は前記露光視野の長手方向に一致させた状態で前記照明光で前記基板を露光することを特徴とするデバイス製造方法。

#### 【請求項 26】

前記マスクに形成されたガートバターンを、前記「11-2」結晶軸またはこれと等価な結晶軸と平行となるように、前記基板上に露光することを特徴とする請求項 25 に記載のデバイスの製造方法。

#### 【請求項 27】

前記マスクに形成されたガートバターンを、前記「11-2」結晶軸またはこれと等価な結晶軸と直交する「11-2」結晶軸またはこれと等価な結晶軸を、前記第 2 方向又は前記露光視野の長手方向に一致させた状態で前記照明光で前記基板を露光することを特徴とするデバイスの製造方法。

#### 【請求項 28】

前記マスクに形成されたガートバターンを、前記「00-1」結晶軸又はこれと等価な結晶軸と実質的に平行となるように、前記表面に垂直な方向が「110」結晶軸にほぼ一致するシリコン結晶基板を用い、前記第 1 方向又は前記露光視野の長手方向に一致させた状態で前記照明光で前記基板を露光することを特徴とするデバイス製造方法。

#### 【請求項 29】

前記表面層はシリコン結晶層であることを特徴とする請求項 29 に記載のデバイス製造方法。

【請求項 30】

前記表面層はシリコン結晶層であることを特徴とする請求項 29 に記載のデバイス製造方法。

【発明の詳細な説明】

【0001】

本発明は、半導体集積回路、液晶表示素子、薄膜磁気ヘッド、その他のマイクロデバイス、又はフォトマスク等をフォトリソグラフィ技術を用いて製造する際に使用される露光装置及び露光方法並びにデバイス製造方法に関する。

## 【従来の技術】

半導体集積回路、液晶ディスプレイ等の電子デバイスの微細パターンの形成に際しては、形成すべきパターンを4～5倍程度に比例拡大して描画した、レチクル（マスクとも呼ぶ）のパターンを、投影露光装置を用いて、ウエハ等の被露光基板上に縮小露光転写する方法が用いられている。

## 【0003】

転写する投影露光装置は、半導体集積回路の微細化に対応するために、その露光波長を、より短波長側にシフトしてきた。現在、その波長はKrFエキシマレーザーの248nmが主流となっているが、より短波長のArFエキシマレーザーの193nmも実用化段階に入りつつある。そして、さらに短波長の波長157nmのF<sub>2</sub>レーザーや、波長126nmのヒドロレーザー等の、いわゆる波長範囲と呼ばれる波長範囲の光源を用いる投影露光装置の提案を行なわれている。

## 【0004】

また、短波長化のみでなく、光学系の大開口数(NA)化によつても高解像度化は可能であるで、光学系のより一層の大NA化開差もなされている。なお、高解像度の実現には、投影光学系の収差の低減が必要である。従つて、投影光学系の製造工程では、光の干涉を利用した波面収差計測を行ない、残存収差量を露光波長の1/1000程度の精度で計測し、その計測値に基づいて投影光学系の調整を行なつてゐる。

## 【0005】

このような大NA化や低収差化は、視野が小さい光学系実現が容易である。但し、露光装置としては、視野（露光フィールド）が大きいほど、処理能力（スループット）が向上する。そこで、小視野ではあるが大NAの投影光学系を用いて、なおかつ実質的に大きな露光フィールドを得たために、露光中に、マスクとウエハを、そのまま対走査するスキャン型露光装置が最近の主流となつてゐる。

## 【0006】

スキャン型露光装置に使用される投影光学系は、一般的に一方に向かって直交する方向に傾かれた長方形型の良像範囲（露光視野）を有する。このような光学系には、反射光学系が使われる場合もあるが、屈折光学系を採用することが一般的である。この場合、上記長方形の露光視野は、円形のレンズの組み合わせからなる屈折光学系の本来の良像範囲となることは限らないので、露光視野も円の直径を含む、かつその円に内接する長方形となるのが一般的である。その理由は、このような長方形視野が、視野の長辺の長さを最大に引き、最も効率が良いからである。

## 【0007】

ただし、投影光学系として反射屈折光学系を採用する場合には、投影光学系の良像範囲となるのは限らないので、露光視野も円の直径を含む長方形となる場合もある。その理由は、この長辺方向と直交する位置を中心とする長方形となることはない。

## 【0008】

相対走査（スキャン）を行なう方向は、この長辺方向と直交する方向である。従つて、長方形短辺方向の投影光学系の視野は、この相対走査によって拡大されるので、短辺方向の視野の狭さが問題となることはない。

## 【0009】

【発明が解決しようとする課題】  
上記のように、スキャン型露光装置で露光される露光エリアは、一方向ににおいては投影光学系によって得られるものであり、その位置に応じて投影光学系の結像性能も変化するため、パターンの転写特性も変化する。

## 【0010】

一方、それと直交する方向には、レチクルとウエハの相対走査（スキャン）によつて拡大された方向であり、投影光学系の結像性能は、その方向にについて一様である。

## 【0011】

ところで、一般的に光学系には、その結像特性を劣化させる収差が残存する。投影露光装置の投影光学系では、他の用途の光学系に比べ残存収差が極めて小さいが、ある程度の収差が残存することは避けられない。

## 【0012】

これららの残存収差には、転写像を投影光学系光軸から周辺への放射方向にボカス成分（放射方向成分）と、投影光学系光軸を中心とする同心円方向にボカス成分（同心円方向成分）とがあるが、一般的にはこのうち放射方向成分の方が大きい。

## 【0013】

放射方向成分の収差は、コマ収差の色収差である。コマ収差は、設計上も製造誤差の点からもその補正が難しく、これを完全に無くすることは困難である。倍率色収差の補正には、レンズの2次スペクトル補正のための高価なレンズ材料が必要であり、その完全な補正によりレンズ品質を極めて昇昇してしまう。一方、色収差の影響を低減するには、レンズの供給幅を拡大（拡帯化）で、色収差によりその出力は低下し、從つてウエハ面上での露光光黒度が低下する必要がある等、露光時間を見延しきること（拡帯化）で、レーザーシャンパー（等）の波長幅を拡大（拡帯化）で、その生産性が低下してしまう。また、レーザーの供給化によりその出力は低下し、その後の出力は低下し、從つて照明時間を見延しきること（拡帯化）で、レーザーの供給幅を拡大（拡帯化）で、その定期的な交換が必要になり、レーザーのランニングコストが上昇してしまう。

## 【0014】

本発明は、このような課題に対してなされたものであり、基板上に転写すべきパターンのうち重要なバターンについての高精度転写を可能とするとともに、倍率色収差や一部のコマ収差等の同心円方向成分の収差が残存する光学系を使用しても、從来と同等かそれ以上に微細なバターンの転写を可能とする露光装置並びに露光方法並びにデバイス製造方法の実現を目的とする。

## 【0015】

【課題を解決するための手段】  
以下、この項に示す説明では、本発明を、実施形態を表す図面に示す参照符号に対応付けて説明するが、本発明の各構成要件は、これらを参考符号を示した図面に示すものに限定されない。

## 【0016】

上述した課題を解決するため、本発明の第1の観点によると、マスク（18）に形成されたバターンの像を基板（25）上に転写する走査型の露光装置において、前記マスクと前記基板とを第1方向（Y方向）に沿つて相対的に移動するステージ装置（19、26）と前記マスクを照らす照明光学系（11）と、前記マスクのバターンを前記基板上に投影する投影光学系（24）とを備え、かつ前記照明光学系は、前記マスクを前記基板上に照射される照明光の偏光状態を、前記第1方向に直交する第2方向に平行な偏光方向の直線偏光を主成分とするよう、前記マスクを照明する機能を有する露光装置が提供される。ここで、「直線偏光を主成分とする」とは、当該照明光が当該直線偏光のみを成分とする完全偏光、又は自然光若しくは他の偏光をも含む部分偏光をいう。当該照明光が部分偏光である場合の偏光度としては、80%以上とするとが望ましい。「偏光度」とは、当該部分偏光の全エネルギーに占める当該直線偏光のエネルギーに占める当該直線偏光の方向をいう。

## 【0017】

本発明によると、マスクのバターンが基板に転写される際に、基板に照射される照明光（露光光）の偏光状態が、移動方向としての第1方向に直交する第2方向に平行な偏光方向の直線偏光を主成分とする偏光状態として、マスクのバターンを基板に露光転写するよう

にしたので、マスクに形成されたパターンのうち、当該第2方向に沿う方向に延びるラインパターンについての投影像のコントラストを高くすることができる、微細なパターンの高精度転写が可能となる。

## 【0018】

本発明において、前記照明光学系（1L）は、前記基板上に照射される照明光の断面形状を前記第2方向に長手方向を有するスリット状（長方形状、短冊状）に整形する整形装置（14）を有することができる。これにより、投影光学系の残存収差による悪影響を緩和することができ、さらに高精度転写が可能となる。なお、前記マスクと前記基板は結像関係にある（すなわちマスクのパターンが投影される）ので、前記基板上において照明光の断面形状をスリット状にすることは、前記マスク（18）に照射する照明光（14）の断面形状をスリット状とすることで実現できる。

## 【0019】

これらの場合には、前記ステージ装置（19, 26）は、前記マスク（18）に形成されたパターンのうち、ラインパターン（32～34）の長手方向と前記第2方向（X方向）とが実質的に平行となるよう、前記マスクを保持することができ、前記ラインパターン（14）が直交する方向（例えば、前記ラインパターンの長手方向と前記第2方向とが実質的に平行となる方向）に直交するべき主要なラインパターンの断面形状をスリット状とすることで実現できる。

## 【0020】

本発明において、前記照明光学系（1L）は光源（1）から供給された光（10）を、前記投影光学系（24）を介して、前記第2方向（X方向）に平行な偏光方向の直線偏光を有する照明光として前記基板（25）上に照らすための調整装置（5）を有することができる。照明光学系（1L）に光を供給する光源（1）が、特定の方向に平行な偏光方向の直線偏光を主成分とする光を射出する場合には、前記調整装置（5）としては、前記基板（25）に照射される照明光の当該直線偏光（たとえば2分の1波長版）を用いる。但し、そのような偏光面を回転する偏光回転装置（5）を用いて、該投影光学系（1L）との光学系位置関係を適宜設定して、前記第2方向に平行な偏光方向の直線偏光を主成分とする照明光を、該投影光学系を介して該基板上に射出するようでもいい。また、光源（1）に光を供給する光源（1）が、自然光その他の偏光（円偏光、梢円偏光）を射出する場合には、前記調整装置（5）と、して、該光源からの光を前記第2方向に平行な偏光方向の直線偏光を主成分とする照明光に調整する直線偏光装置（例えば、直線偏光子、4分の1波長版）を用いる。

## 【0021】

本発明において、前記照明光学系（1L）は、前記投影光学系（24）を介して前記基板（25）に照射される照明光を、前記第2方向に平行な偏光方向の直線偏光を主成分とする照明光とするか、自然光又は円偏光あるいは梢円偏光とするかを選択的に切り替える切り替え機構を有することができる。これにより、露光転写するパターンの内容に応じて、適宜な照明光を選択することができる。

## 【0022】

上述した課題を解決するため、本発明の第2の観点によると、照明光（14）のもとで、マスク（18）に形成されたパターンの像を投影光学系（24）を介して基板（25）上に転写する露光装置において、前記投影光学系（24）の露光視野を、長手方向を有する形状に整形装置（14）と、前記照明光（14）の露光方向と前記整形装置（14）との少なくとも一方で調整し、前記基板上における前記投影光学系の露光視野の露光方向と、前記基板に照射される前記照明光の露光方向を、互いに平行にする露光装置（5）とを備えた露光装置が提供される。

## 【0023】

本発明において、前記マスクを前記照明（14）光で照明する照明光学系（1L）は、前記整形装置（14）は、前記照明光学系（1L）に設けられるようになることができる。

## 【0024】

また、本発明において、前記調整装置（5）は、光源からの光を前記基板上において、前記投影光学系の前記露光視野の長手方向に平行な偏光方向の直線偏光を主成分とする照明光に調整することができる。

## 【0025】

また、本発明の露光装置は、前記マスク（18）と前記基板（25）とを第1方向（Y方向）に沿って相対的に移動するステージ装置（19, 26）を有し、前記露光視野の長手方向は、前記第1方向に直交する方向（X方向）であるようになることができる。

## 【0026】

本発明の第3の観点によると、本発明の第1又は第2の観点に係る露光装置において、前記照明光学系は、フジ化物結晶で形成される複数の光学素子を有し、前記複数の光学素子は、前記照明光学系の光軸方向に向って、一部の光学素子の結晶軸と、他の光学素子の結晶軸とが異なることを特徴とする露光装置が提供される。

## 【0027】

この場合において、前記一部の光学素子における前記照明光学系の光軸方向に直交する結晶軸に対して、前記他の光学素子を中心軸として相互に回転して配置するようになる。

## 【0028】

なお、「一部の光学素子の結晶軸と、他の光学素子の結晶軸とが異なる」とは、当該一部の光学素子の照明光学系光軸方向の結晶軸が例えば「[111]」結晶軸である場合に、当該他の一部の光学素子の照明光学系光軸方向の結晶軸が「[111]」結晶軸以外の結晶軸（例えば「[100]」結晶軸）であることをいう。

## 【0029】

複数の光学素子を上記のように所定の關係で配置することにより、該光学素子が有する複屈折性を補正しない相殺することができる、当該複屈折性による照明光の偏光方向や偏光状態に対する悪影響を小さくすることができます。

## 【0030】

上述した課題を解決するため、本発明の第4の観点によると、バーティンが形成されたマスク（18）と基板（25）とを第1方向（Y方向）に沿って相対的に移動させつつ、該マスク（18）のバーティンを投影光学系を介して該基板上に転写する第2方向に長手方向を有するシリコン基板状の照明光があるとともに、前記第2方向に平行な直線偏光を主成分とする照明光が部屋に於ける照明光法が提供される。この場合において、前記マスクに形成された前記バーティンのうち、ラインバーティンの長手方向と前記第2方向とが実質的に平行となるように設定期に於ける照明光法が提供される。

## 【0031】

ここで、「直線偏光を主成分とする照明光」とは、当該照明光が当該直線偏光のみを成分とする完全偏光、又は自然光若しくは他の偏光をも含む部分偏光をいう。当該照明光が部屋に於ける照明光法であると、該部偏光の全エネルギーに占める当該直線偏光の割合をいう。また、「偏光方向」とは、光の電場ベクトルの方向をいう。

## 【0032】

本発明によると、移動方向としての第1方向に直交する第2方向に平行な偏光方向の直線偏光を主成分とし、該第2方向に長手方向を有するシリコン基板状の照明光を用いて露出するようになるので、マスクに形成されたバーティンのうち、ラインバーティンについての投影像のコントラストを高くすることができるとともに、マスク

この結果、ハッターンを基板上に投影する投影光学系の収差による悪影響を緩和することができる。

【003】 上述した課題を解決するため、本発明の第5の觀点によると、照明光(14)のもとで、  
マスク(18)に形成されたバーテンの像を投光光学系(24)を介して基板(25)上に形成する  
装置において、前記投光光学系(24)の露光視野を、長手方向を有する  
形状に整形し、前記照明光(14)の偏光光方向を前記露光視野の長手方向と平行にして、  
前記マスク(18)のバーテンの像を前記基板上に転写することを特徴とする露光方法が提供され

〔 0 0 3 4 〕  
日本本明において、前記マスクに形成された前記パターンのうち、ラインパターンの長手方向と前記監視野の長手方向とが実質的に平行となるように設定した状態で露光するようになることができる。

【0035】 今まで、本発明において、前記マスク（18）と前記基板（25）とを第1方向（Y方向）に沿って相対的に移動させた状態で露光する際に、前記露光視野の長手方向は、前記第1方向に直交するようになります。

卷之三

なお、本原明紙書において、「結晶軸と等価な結晶軸」とは、ある結晶軸に対して、当該結晶軸の指數の順序を入れ替えた結晶軸と、さらにはそれらの各指數の少なくとも一部についての符号を反転した結晶軸であり、例えばある結晶軸が  $[a\ b\ c]$  結晶軸である場合は、 $[a\ c\ b]$ 、 $[b\ a\ c]$ 、 $[b\ c\ a]$ 、 $[c\ a\ b]$ 、 $[c\ b\ a]$ 、 $[-a\ b\ c]$ 、 $[-a\ c\ b]$ 、 $[-b\ a\ c]$ 、 $[-b\ c\ a]$ 、 $[-c\ a\ b]$ 、 $[-c\ b\ a]$ 、 $[a\ b\ -c]$ 、 $[a\ c\ -b]$ 、 $[b\ a\ -c]$ 、 $[b\ c\ -a]$ 、 $[c\ a\ -b]$ 、 $[c\ b\ -a]$ 、 $[-a\ b\ c]$ 、 $[-a\ c\ b]$ 、 $[-b\ a\ c]$ 、 $[-b\ c\ a]$ 、 $[-c\ a\ b]$ 、 $[-c\ b\ a]$ 、 $[-a\ -b\ c]$ 、 $[-a\ -c\ b]$ 、 $[-b\ -a\ c]$ 、 $[-b\ -c\ b]$ 、 $[-c\ -a\ b]$ 、 $[-c\ -b\ a]$ が等価な結晶軸である。

【0040】  
【発明の実施の形態】  
以下、本発明の実施の形態を図面を用いて説明する。  
【0041】

図1は、本発明の実施の形態に係る露光装置の構成を示す図であり、この露光装置は、**図1**、**ステップ・アンド・スキャン型（走査型）の投影露光装置である。尚、以下の説明においては、X-Y-Z直交座標系を参照しつつ、このX-Y-Z直交座標系を設定し、このX-Y-Z直交座標系に対する平行となる紙面に対するX-Y-Z直交座標系は、Y軸及びZ軸が紙面に沿って定められる。X-Y-Z直交座標系は、Y軸及びZ軸が紙面に対して垂直となるY軸及びZ軸が紙面が水平面上に設置され、Z軸が鉛直方向に設置される。Y軸が鉛直方向に設置される。Y軸が鉛直方向に設置される。**

[0042] この実施の形態に係るスキャン型撮影露光装置は、光源 1、照明光学系 11、投影光学系 22、並びにレチクルステージ 19 及びウエハステージ 26 を有するステージ装置等を備えている。

[0043] 航写すべきパターンが形成されたレチクル（マスク）18 は、レチクル定盤 22 上に載置されたレチクルステージ 19 上に被着保持され、レチクルステージ 19 によつてレチクル定盤 22 上を图中 Y 方向に走査可能になつてゐる。レチクルステージ 19 上には、レチクル移動鏡 20 が設けられており、レチクル側レーザー光干渉計 21 による計測値は、不図示のステージ制御装置により、レチクルステージ 19 の動作が構成されている。

[0044] レチクルステージ19に吸着保持されたレチクル18には、照明光学系11により照明光1-4が照射される。レチクル定盤22には、照明光1-4が通過するための開口部23が形成されており、レチクル18を透過した照明光(回折光)は、開口部23を通しての半導体成像装置24に入射する。そして投影光学系24の結像作用により、被露光基板としてのバターンの投影像が形成される。このバターンは、ウエハ25の表面に露布されたフォトレジストを感光し、レチクルバターンはウエハ25表面に転写される。

【0045】 ウエハ25は、ウエハ定盤29に載置されるウエハステージ26に吸着保持され、ウエハステージ26によってウエハ定盤29上を、図中Y方向に走査可能になっている。ウエハステージ26上には、ウエハ側移動鏡27が設けられており、ウエハ側移動鏡27に対向してウエハ側レーザー干渉計28が配置されている。ウエハ側レーザー干渉計28による計測値は、前記ステージ駆動装置に供給され、該ステージ駆動するよう、レチクルステージ26が同期的に移動にしてウエハステージ26はY方向に走査する。なお、ウエハステージ26はY方向に走査する場合にX方向及びY方向に加えて、X方向及びY方向について動作が制御される。

ステップ移動することができるようにになっており、ウェハ2.5上的一面に設置された複数のショット領域にレチクルバーナンの投射像をそれぞれ転写するため、ウェハ2.5をXY方向に順次ステップ移動させつつ、Y方向への走査(スキヤン)露光を繰り返し行なうになっている。

[0046]

KrF(クリプトンフッ素)エキシマーレーザー(波長248nm)、ArF(アルゴンフッ素)エキシマーレーザー(波長193nm)、F<sub>2</sub>(フッ素分子)レーザー(波長157nm)等の光源1から射出された照明光10は、照明光学系11に供給される。

[0047]

照明光学系11の構成は以下の通りである。光源1から供給された照明光10は、偏光ミラー2及び整形光学系3、4により専用され、偏光制御素子(調整装置)5に入射する。偏光制御素子5の詳細については後述する。

[0048]

偏光制御素子5を通して照明光10は、フライアイレンズや回折格子等の第1の屈折均一化部材6に入射する。第1の屈折均一化部材6を射出した光束は、リレーレンズ7、8を経て、フライアイレンズ等の第2の屈折均一化部材9に入射する。屈折均一化部材9の射出側面には、照明開口校り(φ校り)10が設けられている。照明開口校り10として半径が可変な円形校り(虹彩校り)、輪形状校り(虹彩校り)、複数の開口部を有する変形校り等を使用することができる、これらは回転可能なレボルバ上に配置され、該レボルバが適宜に回転・位置決めされることにより、選択的に配置することができるようになつてゐる。

[0049]

照明開口校り10を射出した光束は、リレーレンズ11、折り曲げミラー12、リレーレンズ13を通じて複野校り14に至る。複野校り14(整形装置)は、レチクル18上の照明視野を制限する装置ないし部材である。

[0050]

本露光装置はスキヤン型露光装置であり、露光に際してレチクル18及びウエハ2.5がY方向にスキヤンするので、レチクル18上の照明視野は、図中X方向に短くY方向に長いスリット形状(ここでは、長方形)とする。このため、複野校り14の形状は、折り曲げミラー17の反射特性を考慮して、図中X方向に長くY方向に短い長方形となる。なお、スリットの幅を調整するため、複野校り14の2方向の両端を規定する校りは、それぞれZ方向に移動可能な構成とするべく構成している。複野校り14を通過した光束は、リレーレンズ15、16と折り曲げ折り曲げミラー17を経て、レチクル18に照射される。

[0051]

偏光制御素子5は、照明光10の偏光状態を制御するための光学素子であり、その偏光状態を所定の状態に設定する。所定の状態とは、レチクル18上に照射される照明光が概ね直線偏光であり、その偏光方向(光の電場ベクトルの方向)が図中X方向になるようある。図1に示した装置では、偏光制御素子5の射出位置での偏光方向もX方向になるよう設定することになる。

[0052]

通常の投影光学系は、その内部に照明光(露光光)の偏光方向を変化させるような部材(逆長坂や偏光ビームスプリッター)を含まないので、上記の様にレチクル18上照射される照明光の偏光状態を、図中X方向(すなわち投影光学系視野の長手方向)と平行にすれば(一致させれば)、マスクおよび投影光学系を介してウエハに照射される照明光(露光光)の偏光状態も、投影光学系視野の長手方向と概ね平行になる。従つて、以下の説明は、レチクル上に照射される照明光の偏光状態と、ウエハに照射される照明光(結像光)の偏光状態とは、等価であることを前提として行なう。

[0053]

上述のエキシマーレーザー光源やフッ素レーザー光源では、その射出光(照明光10)が露

ね直線偏光になる。そこで、この直線偏光の偏光方向を上記所定の方向に一致させるために、例えば、水晶(二酸化珪素結晶)やフッ化マグネシウム結晶等の複屈折性を有する光学材料よりもなる1/2波長板を、所定の方向で挿入する。なお、光源1と照明光学系11との光学的な相対位置関係において、光源1から照明光学系11に供給される照明光10の偏光方向がはじめから上記所定の方向(X方向)と一致している場合には、あえてこのようないずれも良い。

[0054]

なお、光源1が、ランプやランダム偏光レーザーの様に直線偏光以外の光束を発する場合には、偏光制御素子5として、上記所定の方向の直線偏光のみを透過する偏光フィルターや偏光ビームスプリッタを使用する。

[0055]

ここで、レチクル18に照射する照明光は、完全な直線偏光である必要は必ずしもなく、照明光強度の大部分(例えは、80%程度以上)を所定の直線偏光とすれば、本発明の効果は發揮できる。従つて、上記偏光フィルターや偏光ビームスプリッタを用いる場合には、その偏光選択比は、80%程度以上であれば十分である。また、狭帯化を行わないフックレーザーを光源とする場合には、照明光10は、ある程度の直線偏光になり、それと直交する直線偏光も含まれるが、同様の理由により、その照明光に対してそれ以上の直線偏光化を行なうても良い。

[0056]

図2はレチクルステージ19上に載置された状態におけるレチクルの一例を示す平面図である。図2に示すように、レチクル18のパターン30内には主要なパターン3と、パターン32、33、34が描画されている。これらのパターン32、33、34は、例えは、トランジスタゲート等の線幅が細く、要求される線幅均一性が厳格なパターン、即ち高精度転写が必要なパターンであり、特定の方向に沿つて形成されている。パターン30内には他のパターン(図示省略)も描画されており、当該他のパターンは、例えは、該トランジスタゲートの端部に脱けられる配線パターン、トランジスタゲートであつても動作速度が遅くてもよいパターン32、33、34とは異なる方向に沿つて形成されている。

[0057]

本実施形態では、図2に示されているように、レチクル18を、その主要なパターン32、33、34の延びている方向がX方向に略平行となるようにレチクルステージ19上に吸着保持せしめている。すなわち、転写すべきパターンのうち、その線幅が微細でかつその線幅均一性が非常に重要なパターン32、33、34について、その方向をX方向に設定している。

[0058]

図2において、パターンエリア30中の破線で示した領域31は、投影光学系24の露光鏡野に相当する領域であり、投影光学系24の良好範囲40に内接するとともに、その中心は投影光学系24の光軸AXに一致している。但し、投影光学系24の露光鏡野は投影光学系24の良好範囲40に対して偏心して設定されると、この場合には、露光鏡野の中心と、投影光学系24の光軸AXとは一致しない。照明光学系11によりレチクル18に照射される照明光14は、この領域に照射される。この照明光14の偏光状態は、図中に記号Eで示した通りX方向に偏光方向を有する直線偏光を主成分とする。

[0059]

露光に際して、レチクル18及びウエハ25はその結構関係を保つたままY方向に相対走査(スキヤン)されるので、図2の状態で露光鏡野31内にないパターン(パターン34等)もこの走査により順次露光鏡野31内に入り、ウエハ25に転写される。

[0060]

次に、本発明の特徴の一つであるパターン方向と露光鏡野長辺方向の関係及び照明光偏光方向の関係について説明する。

**[0061]** 図3(A)～(C)及び図4(A)～(D)は、バーナン方向と偏光方向の関係を示すための図であり、図3(A)及び図4(A)は、図中X方向に伸びるバーナン3.6に、それぞれ偏光方向E<sub>1</sub>がX方向に一致する直線偏光I<sub>1,2</sub>と、偏光方向E<sub>2</sub>がY方向に一致する直線偏光I<sub>1,2</sub>とが照射される場合を表わしている。

**[0062]** X方向に伸びるバーナン3.6に回折された照明光I<sub>1,2</sub>は、それぞれ+Y及び-Y方向に回折光を発生させる。これらの回折光は、図3(A)では、0次回折光D0.1、-1次回折光DM1、+1次回折光DP1で示され、図4(A)では、0次回折光D0.2、-1次回折光DM2、+1次回折光DP2で示されている。各回折光の偏光状態は、各照明I<sub>1,2</sub>、I<sub>1,2</sub>の偏光状態が保存されるので、投影光学系2.4の鏡面EP上において、図3(A)中の回折光D0.1、DM1、DP1はX方向の直線偏光になり、図4(A)中の回折光D0.2、DM2、DP2はY方向の直線偏光になる。

**[0063]** このような回折光(上述のようにX方向に伸びるバーナン(X方向のバーナン)からのY方向に広がった回折光)は、投影光学系2.4の結像作用により、鏡面EPを通路後に、その進行方向に再びY方向に屈折され、ウェハ2.5上で再び屈折して、ここにバーナン3.6の像である干涉図が形成される。そして、この干渉図がウェハ2.5に照射(照明)され、ウェハ表面に塗布されたフォトレジスト上に像が記録される。

**[0064]** 上記光束の屈折に併せて、その偏光方向が光束の進行方向と直交する方向に回転する。これは電場方向が常に光の進行方向と直交するという光の物理法則に従うものである。

**[0065]** 図4(A)中の回折光DM2、DP2は鏡面EP上ではY方向の直線偏光であるが、その偏光方向は回折光DM2、DP2の屈折に応じて変化する。図4(B)は、図4(A)のウェハ2.5付近の大図であり、回折光DM2、DP2の偏光方向は、各光束の進行方向に直交する方向となり、Y方向からは、ずれている。但し、回折光D0.2の進行方向はZ方向であるため偏光方向はY方向のまま維持されている。

**[0066]** このような光束による干涉図の強度分布は、各偏光(電場)のY方向成分の和の自乘(エキルギー)(図4(C)中の実線で示す強度分布IM2)と、各偏光(電場)のZ方向成分の和の自乗(エキルギー)(図4(C)中の破線で示す強度分布IM3)との和であり(X成分の和は0である)、図4(D)の強度分布IM4となる。しかしこのとき、回折光DM2、DP2の電場のZ方向成分は両偏光の角度の関係から両者の符号が反転するため、その強度分布IM3は、電場のY方向成分が形成した像の強度分布IM2とは位相がずれ、そのコントラストを低下させてしまう。

**[0067]** 従って、図4(A)に示したように、X方向のバーナンを偏光方向がY方向である直線偏光で照明すると、ウェハ上に照射される照明光(各回折光)の偏光方向が互いに平行でないために、その投影像のコントラストが低下してしまい、微細なバーナンの軸写には適さない。

**[0068]** これに対し、図3(A)中の回折光D0.1、DM1、DP1のY方向成分でX方向に偏光方向を持つ光束の偏光方向は、光束の進行方向がY方向に屈折してもX方向に維持される。そして、図3(B)に示されているように、ウェハ2.5上には、偏光方向が全てX方向に描った回折光D0.1、DM1、DP1が照射され、干涉図が形成される。この干涉図強度分布は、電場のX方向成分の和の自乗により求まり(Y、Z成分の和は0である)、図3(C)中の強度分布IM1の通りとなる。これは、図4(A)の場合と異なり符号の反転した成分がないため、そのコントラストが高いことを意味する。

**[0069]** ところで、上述した実施の形態においては、レチクル1.8にX方向に平行な偏光方向を主

従つて、図3(A)に示したように、X方向のバーナンを、ウェハ上に照射される照明光(各回折光)の偏光方向がすべてX方向になるように、偏光方向がX方向である直線偏光で照明すると、その投影像のコントラストは高く、微細なバーナンの軸写に適する。

**[0070]** 次に、バーナン方向と露光視野3.1の関係について、図5を用いて説明する。図5に示すは、投影光学系2.4の露光視野3.1が示されている。露光視野3.1の形状は、その長辺がX方向に沿い、短辺がY方向に沿った長方形となっている。そして、その中心Cは、前述の通り投影光学系2.4の光軸AXと一致する場合が多い。

**[0071]** このような露光視野3.1上のX方向の端に近い点3.9上の結像特性である点像強度分布は、原理的な回折限界及び投影光学系2.4の残存収差の影響で、投影光学系2.4の放射方向及び同心円方向(図5中の点3.9に対するX方向、Y方向に一致)に、広がり(ボケ)を持つ。図中の点像強度分布6.0、6.1は、それぞれ点3.9の位置での点像強度分布のX方向断面(放射方向断面)及びY方向断面(同心円方向断面)を表わしている。このように点像分布の広がりの幅は、残存収差が同心円方向より大きくなるのが一般的である。残存収差には、各種収差があるが、このうちコマ収差と倍率色収差が、放射方向の点像分布の広がりを、同心円方向への広がりより大きくする主因である。

**[0072]** このうちコマ収差は、設計上も製造誤差の点でも完全に除去することは難しい。また、倍率色収差は、投影光学系2.4を構成するレンズの材料に、色収差除去に好適な材料(例えば、萤石)を多用するなり、投影光学系2.4を、凹面鏡を組み込んだ反射屈折光学系にすることである。このいずれの手法でも投影光学系の製造コストが上昇してしまう問題がある。

**[0073]** 投影光学系には、このような収差が残存するため、露光視野3.1の周辺では、露光視野3.1の長辺方向に平行なバーナン3.7の方が、露光視野3.1の長辺方向に垂直なバーナン3.8に比べて残存収差の影響を受けにくく、より微細なバーナンの記号が可能になる。

**[0074]** 本実施の形態では、軸写すべきバーナンのうち、その線幅が微細でかつその線幅均一性が非常に重要なバーナンについて、その方向をX方向(バーナン3.7の方向)に設定している。軸写像は、上記設計方向の収差の影響を受けなくなる。従って、従来と同じ投影光学系を使用しても、より微細なバーナンを解像することが可能になる。また、照明光学系1.1から照射される照明光も、上記のようなX方向(露光視野3.1の長辺方向に平行な方向)のバーナンに最も強度のあるX方向の直線偏光であるため、従来に比べより一層微細なバーナンを解像することができる。

**[0075]** あるいは、露光するバーナンの微細度が従来と同程度で良いなら、使用する投影光学系2.4の放射方向の残存収差の許容値を、従来の投影光学系に比べて緩めることができるので。特に倍率差許容値の緩和により、投影光学系のコストダウンを図ることができる。

**[0076]** また、投影光学系2.4の色収差補正はそのまままで、光源1のスペクトル幅を緩和することもできる。狭帯域レーザーの場合、スペクトル幅の緩和はレーザー狭帯域化素子の高架化を意図し、レーザー出力の増大とともに、露光装置のランニングコストの削減を可

能とする。

**[0077]** ところで、上述した実施の形態においては、レチクル1.8にX方向に平行な偏光方向を主

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成分とする照明光 $I_4$ を照射するようにしたが、露光するバターンによっては、レチクル $1_8$ 上に照射される照明光 $I_4$ 又は円偏光状態を非偏光（自然光）又は円偏光ないし梢円偏光とすることが好ましい場合もある。そこで、本実施の形態において、偏光制御素子 $5$ を、着脱可能な構成とし、あるいはは照明光の進行方向を回転軸として回転可能な構成とすることが望ましい。

## 【0078】

例えば、光源 $1$ が楕円偏光光の光源を発するレーザー光源であり、偏光制御素子 $5$ として $1/2$ 波長板を使用する場合には、図 $6$ に示すように、偏光制御素子 $5$ を $2$ 枚の $1/4$ 波長板 $5_1$ 、 $5_2$ から構成し、照明光 $I_0$ の進行方向を回転軸としたそれぞれの回転によって、射出される光束 $I_1$ を直線偏光光としたり円偏光光としたりすることができる。

## 【0079】

即ち、射出光 $I_1$ を直線偏光光とする場合には、 $1/4$ 波長板 $5_1$ 、 $5_2$ の互いの長軸方向を揃えると共に、その方向を入射光 $I_0$ の偏光光方向と射出光 $I_1$ の所望の偏光光方向の中間に設定すれば良好く、射出光 $I_1$ を円偏光光とするには、光源側の $1/4$ 波長板 $5_1$ の長軸方向を入射光 $I_0$ の偏光光方向と一致させ、他方の $1/4$ 波長板 $5_2$ の長軸方向を、上記偏光光方向に対して $45$ 度回転した方向に設定すれば良い。

## 【0080】

また、光源 $1$ が非偏光光を射出するものである場合には、偏光制御素子 $5$ としての偏光フィルタや偏光ビームスリッタを装備することで、レチクル $1_8$ 上に照射される照明光 $I_1$ の偏光状態を可変することができる。

## 【0081】

なお、本実施の形態では、マスクと基板とが相対移動した状態でマスクのバターンを基板へ転写し、基板を順次ステップ移動させることで、アンド・スキヤン方式の露光装置にて説明したが、長辺方向と短辺方向とを備える形状の露光視野を用いて、マスクと基板とが静止した状態でマスクのバターンを基板へ転写し、基板を順次ステップ移動させる方法と、アンド・アンド・リピート方式で露光してもよい。この、ステップ・アンド・リピート方式が適用される露光装置は、ステップ・アンド・スキヤン方式の露光装置に対し、マスクと基板とを互いに静止させた状態で露光を行いうる点で異なり、その他の構成は、ステップ・アンド・スキヤン方式の露光装置と同じ構成にすることができ。このステップ・アンド・リピート方式の露光装置において、本発明を適用する場合には、マスクのバターンを照明光の偏光方向を偏光制御素子 $5$ で調整すると共に、複野校り $1_4$ を照明光学系の光軸周りに回転させて、投影光学系の露光視野の最邊方向と照明光の偏光方向とを互いに平行するなど可能である。また、光源から供給される照明光の偏光方向がはじめから所定の方向と一致している場合には、複野校り $1_4$ を回転させるだけでもよい。

## 【0082】

なお、露光装置の光源を、 $F_2$ レーザー等の真空紫外光とする場合には、使用するレンズ等の透光光学部材の材料は真空紫外光に対する透過性の高い、萤石等のフッ化物結晶か、フッ素添加の石英のような、いわゆるモディファイド石英を使用する。また、光路については、真空紫外光に対する透過率の高い希ガスや萤石ガスでガス置換して使用する必要がある。

## 【0083】

ところで、 $F_2$ レーザーを光源とする露光装置では、透過率の関係上、照明光学系や投影光学系に採用されるレンズとして使用可能な材料は、実質的に萤石に限定される。萤石は立方晶系に属する結晶であり、從来は結晶固有の複屈折は発生しないと考えられていたが、 $2001$ 年の $5$ 月のInternational SEMTECH (Semiconductor Manufacturing Technology Institute) が主催した $157\text{nm}$ シンボルニア州ナボントで開催)において、真空紫外域では、萤石も結晶固有の複屈折を有することが、NIST (National Institute of Standards and Technology) における本発明者等の論文等で報告されており。

gy：米国国立標準技術研究所）より発表された。

## 【0084】

従来のランダム偏光照明を使用する露光装置においては、照明光学系を構成するレンズ材料の複屈折は、最終的な成像性能には殆ど影響しない。従つてこれまで、照明光学系に配置される萤石レンズの固有複屈折が問題にされることもなかった。

## 【0085】

しかしながら、本発明のように、マスクバターンを直線偏光で照明天するようにした場合、照明光学系内の萤石レンズの固有複屈折に伴う偏光光方向の回転が、問題となる恐れがある。すなわち、萤石レンズの固有複屈折が、 $1/4$ 波長板や $1/4$ 波長板のようくに作用して、マスクバターン面を照明する照明光の偏光光方向が、所望の方向からズレてしまふ恐れがある。また、マスクバターン面内の場所に応じて、照明光の偏光状態が異なる場合もあらう。従つて、 $F_2$ レーザーを照明光源とし、照明光学系に萤石のような結晶材料を採用した露光装置においては、以下のような対策を講じることが望ましい。

## 【0086】

しかしながら、照明光学系の中に配置される萤石レンズ（S枚）のうち、所定の何枚か（A枚とする）の光軸を結晶軸の〔111〕軸と一緒にさせ、かつそのうちの所定枚（a枚とする）のレンズと渡りのレンズ（A-a枚）とは、光軸を回転中心として、その結晶軸が互いに $60$ 度回転するように配置し、残るB枚（＝S-A枚）のレンズは、そぞのレーベルを結晶軸の〔100〕軸と一緒にさせ、かつそのうちの所定枚（b枚）のレンズと渡りのレンズ（B-b枚）とは、光軸を回転中心として、その結晶軸が互いに $45$ 度回転するように配置するなどの対策を施すことが望ましい。

## 【0087】

図 $7$ は、一例として $4$ 枚の照明光学系内のレンズに対して上記対策を施した場合を示しておき、照明光学系の光軸LAXに沿って並ぶ $4$ 枚のレンズ $L_1$ 、 $L_2$ 、 $L_3$ 、 $L_4$ は、いずれも萤石からなるレンズである。このうちレンズ $L_1$ 、 $L_2$ は、その光軸（照明光学系の光軸LAXと一致）が萤石結晶の〔100〕軸と一緒にするレンズであり、かつ両者のレンズ面内方向（光軸LAXと直交する面内）での萤石結晶の結晶軸（〔010〕軸及び〔001〕軸）は、図示した通り $45$ 度回転した関係になっている。

## 【0088】

また、レンズ $L_3$ 、 $L_4$ は、その光軸（照明光学系の光軸LAXと一致）が萤石結晶の〔111〕軸と一緒にするレンズであり、かつ両者のレンズ面内方向（光軸LAXと直交する面内）での萤石結晶の結晶軸（〔0-11〕軸、及び〔-110〕軸）は、図示した通り $60$ 度回転した関係になっている。

## 【0089】

照明光学系にこのような、対策を施すことで、マスクバターン面での照明光の偏光状態を、所望の直線偏光にすることができる、本発明の効果を十分に發揮することが可能となる。

## 【0090】

なお、萤石が投影光学系内のレンズに採用された場合において、固有複屈折が投影光学系の結像性能に与える影響については、使用する各種石レンズの光軸をどの結晶軸と一致させかかる、あるいは、各レンズを光軸を回転中心として何度回転させて配置するかを最適化することにより解決可能なことが、 $2002$ 年 $3$ 月のSPIE (International Society for Optical Engineering Micro lithography Symposium)における本発明者等の論文等で報告されている。

## 【0091】

なお、上述した実施形態では、投影光学系の内部には、照明光（露光光）の偏光方向を変化させてきたような部材（波長板や偏光光ビームスプリッター）を含まないことを前提として説明してきたが、ある種の反屈折光学系では、その中に波長板や偏光光ビームスプリッターなどの偏光状態変更部材を含むものも存在する。この場合にも、投影光学系の露光視野はリストリートされとなることが多い。ただし、レチクルに照射される照明光の偏光状態と、ウエ

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〔一〇九二〕  
本発明を、そのような不安定光学系を有する露光装置に適用する場合には、レチクルに照射される照明光の偏光状態を、上記投影光学系を通して最終的にウエハ面上に照射される照明光（露光光）の偏光状態が、ウエハ面での露光視野シリットの長手方向と平行になるように設置することが望ましい。逆に、露光視野シリットの照明光の長手方向と平行であると、投影光学系による偏光状態が上記偏光状態変換部材により変更されると、ウエハに入射する照明光（露光光）の偏光状態が、好ましくない。

【0098】 ながら、 $[1-10]$  軸又はこれに等価な軸は、結晶の $<111>$ 面内で、それぞれ $120^{\circ}$ 角度の角度で交わる3方位である。従って、この方位に直交する $<111>$ 面内の方向、すなはち $[11-2]$  結晶軸やこれと等価な $[1,1-2]$  結晶軸等)に平行に、ゲートバッテーンの長手方向を形成すると、 $[2-1-1]$  結晶軸、 $[2-1-1]$  結晶軸等)に平行に、ゲートバッターンの長手方向を、移動度の大きな $[1-10]$  軸方位と一致させることができ、C-MOSFETの電流発生が可能となる。

のバターン方位は、レチクル外形の正方形の辺の向きに揃えることが好ましい。しかし、上記の結晶のく111面内で、それぞれ120度の角度で交わる3方位の「[1-1-10]」軸又はこれに等価な軸のうちの1つを、レチクル外形の1つに一致させると、他の2方位は、レチクルバターンの形成精度上、好ましくない方位になってしまいます。従つて、表面には、垂直な結晶軸が「[111]」軸であるウエハを使用してより高速なC-MOS-LSIを実現する場合、実質的に使用可能なゲートバターンの長手方向は、1方向（[−112]）軸及びこれと等価な軸方向の中のいずれか1方向）に揃える必要が生じる。以下、この点に

[0094] ついで考察する。  
[0100] 図8(A)は、表面に垂直な結晶軸が[111]軸であるシリコンウエーハ表面内におけるシリコン結晶の方位を表わす図である。すなわち、ウエハ表面は、シリコン結晶の<111>面に一致している。図示した通り、[111]軸は、紙面に垂直(すなわちウエハ表面に垂直)な方向であり、ウエハ面内には、電子及びホールの移動度が大きくなる[110]軸と等価な結晶軸([0-11]軸、[-110]軸、[-110]軸)が120度の角度間隔で並んでいる。なお、同図ではウエハの回転方向を所定の[111]軸が120度の角度間隔で並んでいる。

[0095]

あつても波長でない通常の光学系であつても、フォトレジストの屈折率が同じであるため、同一波長においては、両者で同一の屈折率（露光光）の 0 度光と 1 度光との間の屈折率差が同じである。従って、通常の光学系に比べ、一層微細な（ピッチの細かい）パターンを露光すべき波長の回折光（露光光）の偏光光（露光光）の偏光状態が最もしくないと、レジスト中の各点の回折光の偏光方向のずれが大きいために、一層の像コントラストの低下が生じることになる。

【0096】次に、現在の半導体集積回路の主流であるC-MOS-LSIでは、ウエハ裏面が結晶の裏面に電子デバイスを形成したものが一般的である。C-MOS-LSIでは、シリコンウエハの表面に、n-MOSのトランジスタとp-MOSのトランジスタの対を形成するが、上記のように裏面が結晶の<100>面であるウエハを使用すると、p-MOSトランジスタのホール（正孔）の移動度が低いという問題がある。

【0097】なお、図8(A)中の、破線で囲まれた長方形の領域EXFは、本実施形態の露光装置の撮影光学系の露光視野領域であり、その最辺方向は図中のX方向と一致、すなわち上記の

【0097】一方、ウエハ裏面を結晶の<111>面に一致させたシリコンウエハ（すなわち裏面に垂直な結晶軸が[111]結晶軸であるウエハ）では、その<111>面内の[1-10]軸方位、及びこれと等価な<111>面内の方位への、電子及びホールの移動速度が大きいことから、C-MOS-LSIの一層の高速動作が可能となる。ここで等価な方位とは、各指標の順序が入れ替わった方位およびそれから少なくとも1つの指標の符号を反転させた方位であり、その中で上記通り<111>面内に存在する方位は、[-110]軸方位、[10-11]軸方位、[-101]軸方位、[01-11]軸方位、[0-111]軸方位となる。

【0100】一方、ウエハ裏面を結晶の<111>面に一致させたシリコンウエハ（すなわち裏面に垂直な結晶軸が[111]結晶軸であるウエハ）では、その<111>面内の[1-10]軸方位、及びこれと等価な<111>面内の方位への、電子及びホールの移動速度が大きいことから、C-MOS-LSIの一層の高速動作が可能となる。ここで等価な方位とは、各指標の順序が入れ替わった方位およびそれから少なくとも1つの指標の符号を反転させた方位であり、その中で上記通り<111>面内に存在する方位は、[-110]軸方位、[10-11]軸方位、[-101]軸方位、[01-11]軸方位、[0-111]軸方位となる。

方向を、バターンP1, P2のようにレチカル外形辺に平行なX方向及びY方向に設定することが好ましく、現状では一般的にそのような方向のバターンが使用されている。

[0105] 図8(A)のように、表面が<111>面であるウエハを使用する場合には、好ましいゲートバターンの方向が、120度毎の3方向に限定されるので、上記レチカルバターンの描画精度の制約と、トランジスタ動作速度との間に満たすゲートバターンG1の方向のみに限定されることとなる。

[0106] 上述した本実施形態に係る投影露光装置を用いて半導体デバイス、その他の電子デバイスを製造する際しては、本実施形態の投影露光装置が高解像度を提供するバターンの方向と、上記のトランジスタ動作速度及びレチカル描画精度の観点から定まるバターンの方向性を、揃えることにより、より一層の高速動作が可能な電子デバイスを製造することができる。

[0107] すなわち、その表面が結晶の<111>面に一致するシリコンウエハ(すなわち表面の垂直線が「111」軸に一致する)を使用し、該シリコンウエハをそのままの「 $-110$ 」軸が投影光学系露光規野の短辺方向に一致するよう(すなわちその「11-2」軸が投影光学系露光規野の長辺方向に一致するよう)に投影露光装置のウエハステージ(26)上に載置し、レチカル上の微細なゲートバターンの長手方向を、投影光学系露光規野の長辺方向に一致するよう(すなわち電子及びホールの移動度の大きさ方向と直交するゲートバターンの長手方向がシリコン結晶の「001」軸又はこれと等価な軸と平行であるトランジスタ)のゲートバターンを、より微細にかつ高精度で転写することが可能になる。

[0108] これにより、シリコン結晶上で高速動作に適した方向のゲートを、より微細な線幅で、より高精度に露光転写することが可能となり、電子デバイスの性能を大幅に向上することが可能になる。

[0109] なお、上記の露光中の結晶の指數は、ウエハ表面に対して垂直上方の方位を「111」軸方向とし、これをもとに他の軸の指數を決定したが、この軸を、「11-1」軸や「11-1」軸等の、「111」軸と等価な軸(指數の順序を並び替えた軸及び一部の指數の符号を反転した軸)として、他の軸の方位を表記しても、本質は全く変わらない。従って、図8(A)に示したシリコンウエハ表面の「0-11」軸、「-110」軸、及び「-101」軸についても「111」軸と等価な面と等価な面内に存在する「110」軸と等価な軸であつても良い。また、投影光学系の露光規野長辺方向に合致するべき軸も、<111>面と等価な面内に存在すれば、どの結晶軸でも構わないことは言うまでもない。

[0110] 本実施形態の走査型露光装置は、その投影光学系の露光規野長辺方向と照明光の偏光方向が概ね一致しているため、露光規野長辺方向と平行な方向を持つバターンについて、解像度やコントラストが優れている。従って、その表面に垂直な結晶軸が「111」軸であるシリコンウエハに、1方向に横たったゲートバターンを形成するのに特に好適であり、加えて、その表面に垂直な結晶軸が「111」軸であるシリコンウエハへの結晶方位を、露光規野長辺方向と「11-2」軸及びこれと等価な軸と等価な面内の軸方位の中のいずれか一方位が平行になるように設定することにより、上記の好ましい条件を満たす結果、高速動作が可能な電子デバイスを製造することができる。

[0111] なお、露光規野長辺方向とウエハの所定の結晶軸とを一致させることは、ウエハ周縁の所定の方向にノッチやオリエンテーションフラッシュを識別マーク等を形成しておくことで、通常の露光装置が行なうアライメントと同様の手法で容易に行なうことができる。

[0112] また、上記のウエハの結晶軸は、表面に垂直な方向と「111」軸が完全に一致している必要は無く、角度で5度程度以内であれば、本発明の効果を十分に發揮することができるので、表面に垂直な結晶軸が「110」軸であるウエハ(以後「110」ウエハといふ)を使用すると、從来C-MOS-LSIで使用されていた、表面に垂直な結晶軸が「110」軸であるウエハ(以後「100」ウエハともいふ)や、上記の表面に垂直な結晶軸が「111」軸であるウエハ(以後「111」ウエハともいふ)を使用した場合よりも、ウエハ上のトランジスタの動作速度を、一層向上させることが可能になる。

[0113] ただし、この場合にも、トランジスタ内の電子又はホールの移動方向を、図9(A)に示した通り、表面に垂直な結晶軸が「110」軸であるウエハ(すなわち表面が結晶の<110>面であるウエハ)の表面のうち、「-110」軸と等価な軸方向に極ね一致させた場合についてのみ動作速度の向上が可能となる。

[0114] 従って、ウエハへ上に形成すべきトランジスタゲートバターンの長手方向は、図9(A)に示したバターンG4通り、図中のX方向に限定すべきである。なお、図9(A)に示したウエハ中の結晶軸方向は、「-110」軸又はこれに等価な軸方向が、図中のY方向に一致し、「00-1」軸又はこれに等価な軸方向と等価なものである。またX方向は、本実施形態の露光装置の投影光学系の露光装置の偏光光の偏光方向と一致し、本実施形態の露光装置の照明光の偏光(直線偏光)の主成分の偏光方向と一致した方向である。

[0115] このように、本実施形態の露光装置に対して、「110」ウエハを上記回転方向(即ち照明光の偏光(直線偏光)の主成分の偏光方向とシリコン結晶の「001」軸又はこれと等価な軸が平行になるような回転方向)で配置することにより、電子及びホールの移動方向を、「110」ウエハ上で電子及びホールの移動度の大きさ方向である「-110」又はこれと等価な方向とするトランジスタ(すなわち電子及びホールの移動方向と直交するゲートバターンの長手方向がシリコン結晶の「001」軸又はこれと等価な軸と平行であるトランジスタ)のゲートバターンを、より微細にかつ高精度で転写することが可能になる。

[0116] これによつて、從来より一層高速な電子デバイス(C-MOS-LSI)を製造することが可能になる。

[0117] 図9(B)は、この場合に使用するレチカル上面図である。そのパターンエンジニア内には、転写すべきパターンの原版が描画されている。ただし、図9(A)のように表面が<110>面であるウエハを使用する場合には、好ましいゲートの方向が1方向に限定されるので、パターン原版の長手方向も、図9(A)中のX方向に平行なゲートバターンG4の方向のみに限定されることになる。

[0118] 例えは、シリコンウエハの表面に、シリコン結晶よりも格子定数の大きなシリコン・ゲルマニウム結晶を薄膜として形成し、その上に再度シリコン結晶を薄膜として形成した場合、最上層の(裏面の)シリコン層は、下層のシリコン・ゲルマニウム結晶の格子定数の影響を受けて引張られ、その結晶格子が伸縮され歪む。その結果、この最上層の(裏面の

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)シリコン層での電子及びホールの移動度が上昇し、すなわちトランジスタの動作速度を向上することができる。

#### 【0121】

一般には、この歪みは、ウェハ面内で墨ね等方に生じるが、所定のプロセスにより、この歪みを所定の1方向に限定することも可能である。例えば、上記のシリコン・ゲルマニウム膜の成膜及びその上層へのシリコン膜の成膜を、シリコンエハの【110】面上の上で行なうと、その歪み方向も、ほぼ1方向に限定される。

#### 【0122】

この場合、トランジスタのゲートバーンの長手方向は、上記電子あるいはホールの移動

度が最大となる方向に対して、直交する方向に合致させることが望ましく、シリコンウエ

ハ上の全てのトランジスタのゲートバーンの長手方向が、1方向に向うことが可能

となる。

#### 【0123】

この場合、トランジスタのゲートバーンの長手方向は、上記電子あるいはホールの移動

度が最大となる方向に対して、直交する方向に合致させることが望ましく、シリコンウエ

ハ上の全てのトランジスタのゲートバーンの長手方向が、1方向に向うことが可能

となる。

#### 【0124】

本実施形態の露光装置では、投影光学系の長方形のゲートバーンの長辺方向に平行な直線偏光光を多く含む照明光でウエハを露光するので、上記の非等方的な歪みシリコンウエハの露光に際して、トランジスタのゲートバーンを、投影光学系の露光視野の露光視野の長辺方向（第2の方向）に平行に設定することで、從来の露光装置及び露光方法に比べて、より線幅制御性が良好で、高精度で微細なゲートバーンの転写が可能になる。すなわち、上記非等方的な歪みシリコンウエハの、その表面での電子またはホールの少なくとも一方の移動度が最大となる方向と、本露光装置が供給する横ね直線偏光光の偏光方向（電場の方向）とを、直交させて配置して露光を行うことで、製造する電子デバイス中のゲートバーンの線幅及び線幅の均一性を、從来よりも一層向上させることができ、歪みシリコンウエハの採用と相俟って、從来の電子デバイスより一層高速な電子デバイスを製造することが可能となる。

#### 【0125】

なお、以上の実施形態では、電子デバイスとしてC-MOS-LSIを想定して説明したが、そのようなC-MOS-LSIに限られるものではなく、本発明は、n-MOSやp-MOSや他のデバイスの製造にも同様に適応されるべきものであることは言うまでもない。

#### 【0126】

また、露光装置の用途としては半導体装置製造用の露光装置に限られることがではなく、例えば、角型のガラスフレートに液晶表示素子バーンを露光転写する液晶用の露光装置や、薄膜磁気ヘッドを製造するための露光装置にも広く適用できる。さらには、マイクロマシン、DNAチップ、マスク等を製造するための露光装置にも適用することができる。

#### 【0127】

本実施形態の露光装置は、複数のレンズ等から構成される照明光学系、投影光学系を露光装置本体に組み込み光学調整部品からなるレチクルステージやウエハステージを露光装置本体に取り付けて配線や配管を接続し、さらに総合調整（電気調整、動作確認等）をすることにより製造することができる。尚、露光装置の製造は温度及びクリーン度等が管理されたクリーンルーム内で行なうことが望ましい。

#### 【0128】

半導体デバイスは、一概にデバイスの機能・性能設計を行うステップ、この設計ステップに基づいたレチクルを製作するステップ、シリコン材料からウエハを作成するステップ、露光装置によりレチクルのバーンをレジスト墨液のみのウエハに露光転写して現像する

ステップ、デバイス組み立てステップ（ダイシング工程、ボンディング工程、パッケージ工程を含む）、検査ステップ等を経て製造される。

#### 【0129】

なお、本発明は、上述した実施形態に限定されるものではなく、本発明の範囲内で種々に改変することができることは言うまでもない。

#### 【0130】

【発明の効果】  
以上本発明によれば、基板に入射する照明光（露光光）を、マスク及び基板の移動方向に直交する方向に平行な偏光方向の直線偏光光を主成分とする照明光で照明しつつ、該基板を露光するようとしたので、当該移動方向に直交する方向に沿う方向に延びるラインパターンについての投影像のコントラストを高くすることができ、微細なバーナーを高精度転写することができる。

#### 【0131】

また、露光転写するバーナーの微細度が従来と同程度で良いなら、投影光学系の放射方向の残存収差の許容値を、從来の投影光学系に比べて緩めることができ。特に倍率収差許容値の緩和により、投影光学系のコストダウンを図ることができるので、本発明により、安価な投影露光装置を提供することができる。

#### 【0132】

さらに、投影光学系の色収差補正是そのまままで、光源のスペクトル幅を緩和することもできる。共振化レーザーの場合、スペクトル幅の緩和はレーザー紫外部化素子の簡素化を意味する。共振化レーザーの場合は、レーザー紫外部化素子寿命の延長をもたらし、露光装置の処理能力の向上し、レーザー出力の増大と共振化素子寿命の増大と共振化素子寿命の延伸したので、高速動作が可能なデバイスを製造することができる。

#### 【0133】

また、マスク及び基板の移動方向に直交する方向に平行な偏光方向の直線偏光光を主成分とする照明光を用いて露光することに加えて、基板上に露光転写するゲートバーン等のバーナーの方向を基板の結晶軸との関係で最適化したので、高速動作が可能なデバイスを製造することができる。

#### 【図面の簡単な説明】

【図1】本発明の実施形態に係る露光装置の概略構成を示す図である。

#### 【図2】本発明の実施形態の露光装置の平面図である。

#### 【図3】本発明の実施形態の露光装置のバーナー方向と偏光光方向の関係を示す図である。

#### 【図4】本発明の実施形態の露光装置のバーナー方向と偏光光方向の関係を示す図である。

#### 【図5】本発明の実施形態の露光装置を示す図である。

#### 【図6】本発明の実施形態の露光装置の構成の一例を示す図である。

#### 【図7】本発明の実施形態の露光装置の構成の一例を示す図である。

#### 【図8】本発明の実施形態の露光装置の構成の一例を示す図である。

#### 【図9】本発明の実施形態の露光装置の構成の一例を示す図である。

#### 【符号の説明】

1…光源  
5…露光制御素子（調整装置）

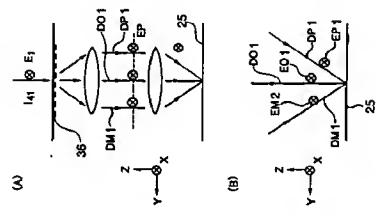
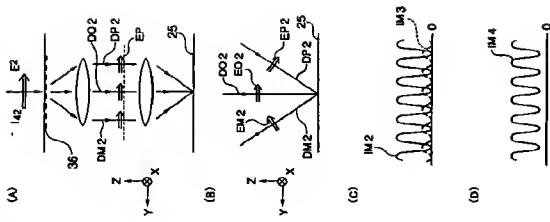
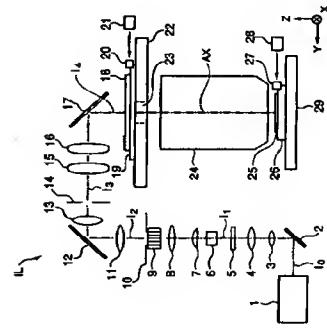
14…露野枚り（整形装置）

18…レチクル（マスク）

19…レチクルステージ（ステージ装置）

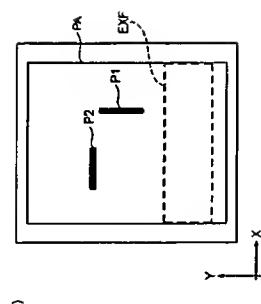
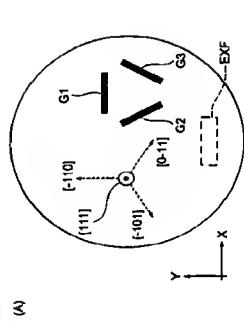
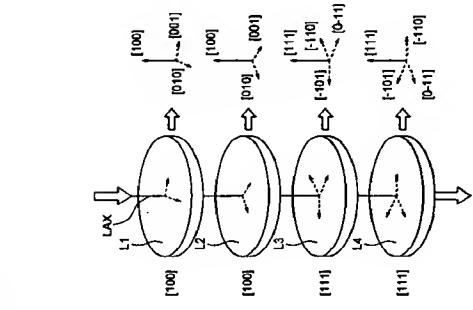
24…投影光学系

2 5 … ヴエハ (感応基板)  
 2 6 … ヴエハステージ (ステージ装置)  
 3 1 … 露光视野  
 3 2 ~ 3 4 … 主要バターン  
 1 0 ~ 1 4 … 黒明光

[図 3]  
図 3[図 4]  
図 4[図 1]  
図 1

[ 図 7 ]  
図 7

[ 図 8 ]  
図 8



[ 図 9 ]  
図 9

